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FINAL REPORT

RHEOLOGIC PROPERTIES OF THE SOLID EARTH

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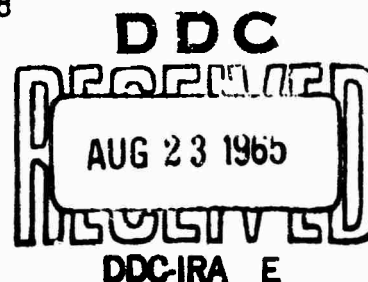
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Personnel

The following persons have been working on the Contract:

Markus Båth, Project Scientist, variable part-time;

Seweryn J. Duda, full-time.

The research has been made at the Seismological Institute, Uppsala, except that S.J. Duda carried on the work at the Seismological Laboratory, California Institute of Technology, Pasadena, California, in the interval Jan. 1-Sep. 27, 1964.

Introduction

This report presents the development and conclusions of three years' research of the rheologic properties of the solid earth. The work consisted of the following parts:

1. Strain-release studies of the circum-Pacific seismic belt.
2. Laboratory studies of the behaviour of scale models under stress.
3. Development of a method to measure stress variations in the crust caused by earth tides and other related phenomena.

4. Application of array-station records to studies of wave propagation and seismicity.

Of the total time of 3 years, approximately 2 years have been spent on item 1 and 1/2 year on each of the items 2 and 4. The somewhat uneven distribution on the various items is a reflection of several factors, such as availability of facilities and our judgment on the relative importance of various problems.

Of the four items mentioned, 1-3 were included in the Contract. Item 4 was added during S.J. Duda's visit to Pasadena, and it has also close connections to the main topic of the Contract. Each of the four items will now be treated in some detail. Complete accounts of all results can be found in the papers published under the Contract and listed below.

1. Strain-release studies of the circum-Pacific belt

a. Statement of the problem

The strain-release method has been applied to the investigation of earthquake sequences since about 15 years ago. It was first proposed by Benioff (1951) in connection with aftershock sequences, following most of the larger earthquakes. This method made it possible to treat the aftershocks not as single, independent phenomena, but as events connected genetically with each other. Later, the method was applied by Benioff also to series of earthquake other than aftershock sequences.

The stimulus to the present project was the use of Benioff's method in a study of the famous Aleutian Islands 1957 aftershock sequence, performed at the Seismological Institute, Uppsala, in 1960-61. See Duda (1961, 1962) in References below. This study revealed several features of the aftershock sequence, not observed for any sequence before. As a consequence, a number of aftershock sequences in other parts of the world were studied with the purpose to find out to which extent the observed features have general validity.

We aimed at exploring the dynamics of strain release in earthquake sequences, and also the mutual dependence of earthquake activity on adjacent, but distinctly separated fault systems.

The original method of strain-release studies, although still used by some seismologists, turned out not to be sufficiently well founded in some aspects. An investigation of the method was undertaken, and consequently in the later stage of the project preference is given to the concept of strain-energy release, instead of strain release.

The world-wide distribution of the strain release in dependence of focal depth provides information about the distribution of stress accumulation with depth and the rheologic conditions in the upper part of the earth, but concerns also the earthquake mechanism in different depths.

The secular strain-energy release in earthquakes since the beginning of instrumental seismology provides information about the dynamical relations of earthquake activity in different parts of the world and in different depth ranges. From the secular seismic activity some inferences can be drawn about the mechanism of aftershock generation.

In short, we may say that our problem has been to explore the mutual relations between earthquakes, both in space and in time. This problem derives from the convincing evidence that such relations really exist, but that their exact nature is still obscure. The problem has been attacked in all possible ways, as outlined here, and at least we have approached the solution with a few steps. It must be understood that this is really an intricate problem where so many factors enter, of which all are perhaps not even known to-day. The work achieved in this respect under the present Contract probably represents one of the most concentrated efforts in recent years to throw light on these problems, at least on a more global scale.

These problems will in the long run certainly also prove to be of

very great practical application, namely for earthquake prediction - a problem which in recent years has been taken up with renewed interest in several countries.

b. Oscillation patterns in aftershock sequences

Earthquake activity provides important information about the physical conditions in the earth's upper part. It is of special interest to carry out investigations for the area with the highest activity - the circum-Pacific belt, particularly of aftershock sequences, characterizing an increase of the earthquake activity in a certain region and for a certain time interval. Therefore, part of our research was devoted to studies of strain release in the circum-Pacific belt during aftershock sequences.

For most of the well recorded aftershock sequences it is observed that the aftershock area is elongated and most strain release occurs near the horizontal ends of this area. This may be expected theoretically from an analogy to the stress field around a slit in a perfectly elastic body (Anderson 1951; V.I. Keilis-Borok 1960). The location of the ends of the aftershock area with increased strain release is determined by the orientation of the fault zone and the direction of the stress field. A horizontal compressional field will give rise to an increase of stress at the horizontal ends of a dipping fault, having an oblique strike relative to the compressional field direction, and to a strike-slip motion. On the other hand, a compressional field perpendicular to the strike of a dipping fault will give rise to an increase of stress at the vertical ends (i.e. the upper and lower ends) of the fault surface, and to a dip-slip motion. For both these extreme cases an oscillation of the strain release between the two ends has been observed: in the first case for the Aleutian Islands 1957 sequence (Duda 1961, 1962), and in the second case for the Kamchatka 1952 sequence (Tarakanov 1961).

The oscillation pattern is revealed by a negative correlation

between the time variations of strain-energy release at the two ends of the aftershock area. The oscillation overlaps the overall decrease of the intensity of strain release with time during the aftershock sequence. The oscillation periods can be measured. The period is generally increasing with time. Thus, the oscillations cannot be considered as free, but as becoming free in course of time: at the beginning of the sequence, when the stress in the aftershock volume is highest, the periods are shortest; with decrease of the stress and release of strain, the periods become longer. This was observed for the oscillations both between the horizontal and the vertical extremities of the aftershock volume.

It is obvious that real conditions can be combinations of these two cases.

We have investigated the following aftershock sequences with respect to possible oscillation patterns:

1. Kern County 1952 (White Wolf fault and Edison fault)
2. San Francisco 1957
3. Desert Hot Springs 1948
4. Chile 1960
5. Kurile Islands 1963
6. Prince William Sound 1964
7. Mongolia 1957

The accumulation of strain release towards the extremities of the fault zone was ascertained in all investigated cases. Sometimes, besides the maxima at the horizontal extremities, a maximum in the middle of the aftershock area was found (White Wolf fault 1952, San Francisco 1957). From fault-plane solutions for aftershocks it is known (Báth and Richter 1958; Aki 1960) that the aftershocks at the horizontal extremities are prevailing of horizontal strike-slip type, whereas the aftershocks in the middle are of vertical dip-slip type. The maximum of strain release observed in the middle of the aftershock zone obviously corresponds

to the maxima at the vertical extremities of the aftershock volume. The vertical extremities cannot usually be discovered directly because of insufficient accuracy in the depth determination of the aftershocks and also because of insufficient separation of epicenters in case of steeply dipping faults. An indirect method had to be applied just for this reason by Tarakanov (1961) to find the oscillation pattern. We were able to establish the existence of an oscillation pattern in five of the cases investigated.

The search for the accumulation of strain release at the extremities of the aftershock zone and for the oscillation pattern between the extremities led to a completely new interpretation of the very well recorded and already thoroughly investigated Kern County 1952 sequence. It was proved that during the aftershock sequence, besides the White Wolf fault also another fault was activated, probably the Edison fault, cutting the White Wolf fault at an acute angle. Our interpretation is in agreement with seismological as well as geodetical and geological published statements.

The Kern County aftershock sequence was a clear instance of a mechanical interrelationship between two different faults. In conclusion of our study of the Kern County 1952 aftershock sequence, we made the following statements:

a) The implicit supposition usually made that earthquake sequences in a given area and a certain time interval are independent of earthquakes in another area nearby but perhaps also remote, in the same time interval, is in need of modification.

β) It is more probable that an aftershock sequence is independent of outside influences in its earlier stage (of the duration of hours or days after the main shock) than in the later stage (reaching hundreds and even thousands of days).

Support for our conclusions is offered by further results reported just below.

### c. Migration patterns

Nearly all strain-release studies of aftershock sequences have so far been concerned only with the aftershock sequence itself, starting after the main shock. As conditions of strain release prior to the main shock may be of equally great importance for a more complete understanding of the phenomena, we initiated such research for a few cases.

A study of strain release in South America before and during the Chilean 1960 aftershock sequence gave some new results on the aftershock occurrence. The area occupied by the aftershock activity starting in 1960 was remarkably inactive for many years before 1960. This implies that during the past years strain was accumulated and not released before 1960 when the very strong and disastrous main shocks occurred and an aftershock sequence started. During 40 months preceding the Chilean earthquake sequence, a repeated northward migration of the maximum strain release took place to the north of the aftershock region. The velocity of the migration increased with time towards the start of the sequence. The migration pattern was destroyed by the beginning of the Chilean earthquake sequence. In particular, the region adjacent to the aftershock area in the north became quiet for more than two years after the start of the sequence.

It turned out that the extremities of the aftershock area are not necessarily fixed in space as found earlier, but can move in course of the aftershock sequence.

The migration pattern was indicated to extend towards north, beyond the region in South America. An indication was found for a similar migration pattern in the seismic belt in the North American continent between Mexico and Alaska.

The direction of migration of the highest intensity of strain release was in both cases from the region of higher stress towards the region with lower stress. In the light of this evidence, the oscillation between the extremities of an aftershock zone can be explained as a repeated

shift of the strain release from the extremity of currently higher stress towards the extremity of lower stress.

In conclusion, it may be stated that a relation of seismic activity exists between nearby areas and also between areas situated up to at least a few thousand kilometers from each other. The increase of seismic activity in one area is accompanied by a simultaneous decrease of activity in adjacent areas. Both the oscillation pattern in aftershock areas and the migration of activity on more "secular" basis are to be considered as special cases of this general rule.

#### d. Strain-release characteristics

The strain-release characteristics reveal features of the aftershock generation process as a function of time. The time derivative of the strain-release characteristics shows the intensity of strain release at any time after the main shock. The strain-release characteristics were constructed for all of the aftershock sequences investigated. As a common feature, the strain-release characteristics show a break 1-10 days after the main shock. The break indicates a sudden increase of the intensity of strain release at that time. The lower intensity of strain release immediately after the main shock cannot at all be explained by incomplete data. After the break, the intensity of strain release decreases in general hyperbolically with time. This offers a possibility to estimate the moment when the aftershock intensity has decreased below a certain level of seismic activity, which can be assumed as normal in the region of the aftershock area (Båth and Benioff 1958). In other words, this moment will define the length of the aftershock sequence.

Some of the strain-release characteristics were reconstructed after the improvement of the method, and presented as "strain-energy release" characteristics (see section g. below).

#### e. Parameters of aftershock sequences

The magnitudes of the main shock and of the aftershocks of the sequences

investigated were determined on the base of records of the Swedish seismograph network. In all cases the magnitude of the main shock was found to be distinctly greater than the magnitude of the largest aftershock. The magnitude difference was found to amount to 1.2 within error limits of magnitude determination, which is in agreement with the so-called Bath's law (Richter 1958, p. 69).

The distribution of aftershock foci allowed us to determine the dimensions of the aftershock volume.

The strain release of the main shock was of the same order as the summary strain release in the aftershocks. The strain energy released in the main shock was always higher than the summary strain-energy release in the aftershocks.

Of particular importance is the b-coefficient in the equation

$$\log N = a - b M \quad (1)$$

which gives the number N of earthquakes with magnitudes  $\geq M$ . This was determined for all aftershock sequences investigated. A large b-coefficient denotes a high proportion of earthquakes with low magnitudes and vice versa. The b-coefficient is discussed below, as also in the paper attached as Appendix to the present report.

An important question is if the recurrence relation (1) can be extrapolated beyond the magnitude range for which the constants have been determined. Investigating an aftershock sequence in Baja California 1963 and an earthquake swarm in Imperial County, California, 1963 (see 4. below) we found the b-coefficient to decrease with magnitude. Therefore, equation (1) cannot be extrapolated beyond the magnitude range for which it has been determined.

#### f. Strain release as function of focal depth

The world-wide strain release in relation to focal depth has been calculated for all earthquakes with magnitudes 7.0 and

above for the time interval 1918-1952. The strain exhibits a pronounced maximum in the uppermost 75 km of the earth. It decreases exponentially with depth between 75 and 400 km, with an unimportant minimum corresponding to the asthenosphere low-velocity layer and another minimum at 275 km. After a pronounced minimum at 400 to 475 km, it increases again approximately exponentially between 475 and 650 km, after which it drops rapidly to zero. The depth curve for the number of shocks is nearly parallel to the strain-depth curve, and the average strain per earthquake shows only an insignificant decrease with depth.

From the strain-release-versus-focal-depth diagram it follows that the shallow and intermediate earthquakes to a depth of say 450 km, form one unity. The deeper earthquakes in the range from 450 to 720 km form another one. This is partially in disagreement with the depth classification used hitherto, when the depth separating intermediate from deep earthquakes is assumed at 300 km. From our result it seems unnatural to group the earthquakes in the range 300-450 km together with those in the range 450-720 km, as these two depth ranges are distinctly separated from each other. On the other hand, it appears natural to put the depth limit between intermediate and deep earthquakes at 450 km, as this separation has not only formal but also physical significance.

There is fairly general agreement that shallow and intermediate earthquakes are due to faulting. However, as shown recently by Benioff (1963), the strain seismometer recordings of deep-focus earthquakes indicated a "source in the form of a sudden contraction of a volume of rock at the hypocenter, such as might result from a sudden change of state" of the material. Thus, the depth limit between intermediate and deep earthquakes assumed at 450 km depth possibly separates earthquakes of different genesis and focal mechanism.

g. "Strain-energy release" instead of "strain release"

An effort was undertaken to improve Benioff's original method for investigation of strain release in aftershock sequences. The basic finding was that the earthquake volume, assumed to be identical with the aftershock volume, increases with magnitude. In Benioff's original method the volume was assumed to be constant, because of lack of information about its dimensions (Benioff's written communication).

Another improvement was the introduction of a revised magnitude-energy conversion formula. The most actual one given by Bath (1958) was adopted.

In conclusion it was found that the strain released in an earthquake is independent of magnitude, within experimental error limits. This implies that the difference in magnitudes of two earthquakes is not due to the difference in the strain accumulated, but to the difference in the volume involved.

The seismic gain ratio, i.e. the ratio between the seismic energy and the elastic strain energy, as defined by Lomnitz, was shown not to be constant, as assumed hitherto, but to increase with magnitude. This means that for larger earthquakes the conversion of strain energy into seismic energy is more efficient than for smaller earthquakes. This problem needs further consideration.

As mentioned under section d. above, some of the earlier strain-release characteristics have been reconstructed, now as characteristics of strain energy instead. The earlier strain-release characteristics exhibited a great variety of forms, and it appeared to be a justified question what their real value was. On the other hand, there are certain indications that the strain-energy characteristics are more uniform in shape, and therefore may have more closer bearing on the physics behind the observed phenomena.

h. Completion of the list of large earthquakes on the base  
of Uppsala records

The most complete list of large earthquakes up to 1952 was published by Gutenberg and Richter (1954) and Gutenberg (1956). The earthquakes from 1897 through 1903 are only incompletely known. The number of earthquakes with magnitude 7.0 and above is complete since 1918, and of earthquakes with magnitude 7.9 and above since 1904. In other words, the number is incomplete in the magnitude range 7.0 through 7.8 in 1904-1917.

We attempted to find earthquakes with magnitude down to 7.0 also for the interval 1904-1917. For this purpose the records of the Seismological Institute in Uppsala were used. The station at Uppsala started operation on October 8, 1904, after installation of a Wiechert seismograph. The instrument has been in practically continuous operation ever since, and all records are stored at the institute. This provided a unique opportunity to complete the list for the largest earthquakes.

The earthquakes with magnitudes 7.0 and above from October 8, 1904, to December 31, 1917, were listed from the Uppsala records. For this time 146 earthquakes could be added to the 138 reported by Gutenberg and Richter (1954). Data on epicenters of the additional shocks were compiled from various sources. The magnitudes determined are based on all appropriate phases which could be identified on the Uppsala seismograms. The magnitudes of the added earthquakes are consistent with the most recent determinations by Gutenberg and Richter (1954) and Gutenberg (1956). The procedure of magnitude determination applied is presented by Båth (1954).

It is difficult to estimate how far the additional earthquakes fill the gap in Gutenberg and Richter's list. Most probably some earthquakes with focal depth greater than normal are still missing, since their identification is difficult from a single station. However, it is our belief that for the interval 1904-1917 practically all shallow earthquakes are now known with magnitudes 7.0 and above in the distance range up to

100° from Uppsala. This range includes the seismically most active regions in the world.

The paper attached as Appendix to the present Report contains a list of all known earthquakes with magnitudes 7.0 and above for the interval 1897-1964, inclusive. The list is the most complete one ever published.

i. Strain energy and b-coefficients in different circum-Pacific regions

For the investigation of secular seismic activity in the circum-Pacific belt, this belt was divided into eight regions. They had to be chosen large enough to allow statistically significant conclusions for each of them, and so that possible differences of their rheologic characteristics could be found. The intensity of strain-energy release, i.e. the strain-energy release per unit time and unit space, was found to be highest in the NW part of the belt. Starting from that region and proceeding around the Pacific Ocean in both directions, the intensity decreases from region to region. It increases again in the SE part of the belt.

This model of circum-Pacific seismicity does not offer support for the hypothesis of the relative rotation of the Pacific Ocean bottom and the surrounding continents. Several other hypotheses could be advanced which could better meet our observations. With references to the oscillation and migration patterns, described in sections b. and c. above, one could suggest an oscillation between the NW and SE concentrations of activity, along both the connecting circum-Pacific belts. However, it must be emphasized that at present this is only a hypothesis but one which deserves further examination.

The maximum magnitude observed in a certain region is correlated with the intensity of strain-energy release, such that the magnitude is

higher for a higher intensity, and vice versa.

The b-coefficients in the recurrence diagrams of each of the circum-Pacific regions were determined. They are correlated with the intensity such that a large b-coefficient corresponds to a low intensity, and vice versa.

If the maximum magnitude observed in a region is a measure of the average stress in the region, such that a large magnitude is found in regions with a high stress, we may conclude from the foregoing, that the b-coefficient is large in regions with low average stress and conversely, it is small in regions with high average stress.

This throws some new light on aftershock sequences.

The b-coefficients in the aftershock sequences in Kamchatka 1952 (Båth and Benioff 1958) and the Aleutian Islands 1957 (Duda 1962) are distinctly greater than the "secular" b-coefficients in the same regions. This implies that aftershocks occur in a volume with reduced stress, if compared with average conditions in the region. This is to be expected from Benioff's (1951) hypothesis on aftershock generation. According to this, the aftershocks are a manifestation of the elastic afterworking of the material, following the release of the pure elastic deformation in the main shock. As a consequence of the main shock, the stress in the earthquake volume (practically identical with the aftershock volume) is reduced. In analogy with the behaviour of the secular b-coefficients in the circum-Pacific regions with a low average stress, the b-coefficients for aftershocks are expected to be greater than the secular b-coefficients in the same regions, just as found from our comparison.

#### j. World-wide seismic energy release per year

The seismic energy release per year in the shallow and intermediate earthquakes in the circum-Pacific belt was decreasing significantly in the interval 1897-1964. There is an indication of a decrease also for deep

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earthquakes in the circum-Pacific belt and for shallow and intermediate earthquakes outside of the circum-Pacific belt.

Besides the overall decrease a striking quietness of seismic activity in shallow earthquakes in the circum-Pacific belt was found for the years 1907-1916. In the same time interval the activity in intermediate earthquakes shows a maximum. Neither is the cause of this negative correlation clear, nor did it repeat in the time interval of 68 years investigated. It is only natural that a search for a periodicity in the yearly strain-energy release world-wide gave a negative result, i.e. no significant periodicity could be ascertained. This does not exclude the possibility for periodicities on a smaller scale of space and time, or on a larger scale world-wide.

#### k. Some remaining problems

It is natural that our investigations on this part of the Contract have not only given some new results, but above all, have indicated some new lines of attack on problems. Even if our application for prolongation of this research has not been approved, we consider it of interest, especially for the sake of completeness, to list briefly some problems which still remain.

Investigations were started on three aftershock sequences mentioned above (Mongolia, 1960; Kurile Islands, 1963; Prince William Sound, 1964), but time did not permit their completion.

Oscillation patterns in aftershock sequences and especially migration patterns on a more secular and global scale should be studied. Especially the latter must be considered of primary importance as a basis for any successful earthquake prediction.

It is only poorly known, how the slip movements on the fault planes in the aftershocks are consistent with each other, and with the slip movement on the fault plane of the main shock. This question is difficult to answer, because the aftershocks are usually recorded on

an insufficient number of observatories to allow fault-plane solutions. Nevertheless, with the increase of the number of observatories, fault-plane solutions for at least major aftershocks will be possible.

Differences found between release characteristics of different aftershock sequences are usually referred to some differences in material or behaviour of stress at different localities. To place such deductions on a more firm basis, it would be extremely important not only to compare sequences in different regions but also sequences of comparable size which have occurred within one and the same region, but at different times. To our knowledge, no such comparisons have so far been made. The Kurile Islands aftershock sequences, starting on Nov. 6, 1958, and Oct. 13, 1963, resp., offer an interesting opportunity for such a comparison. The main shocks occurred in almost the same point and were of about the same magnitude. Another suitable pair of such shocks occurred in the Aleutians on Mar. 9, 1957, and Feb. 4, 1965.

An error-minimizing procedure should be used to approximate the empirical strain-energy release characteristics by mathematical functions, especially as this would facilitate comparisons with stress-relaxation curves determined in the laboratory.

Power spectral analyses of the body waves (P and S) radiated from the aftershock zone at different stages of the aftershock sequence may provide information on possible relations between spectral composition and stress.

## 2. Laboratory studies of the behaviour of scale models under stress

### a. Statement of the problem

The study of earthquake sequences is highly dependent on the registration of the particular earthquakes by a network of seismograph stations. However, even if this is guaranteed, the aftershock sequence starts at an unpredictable place and time. Consequently, only sequences of large earthquakes are generally recorded with sufficient completeness,

whereas the small earthquakes - apart from few exceptions - are recorded far from completely. If an aftershock sequence starts even at a place which can be reached conveniently, a local network of highly sensitive seismographs can only be put into operation hours or days after its beginning. For this reason much valuable information escapes attention.

An earthquake sequence is a process which cannot be influenced artificially. Thus, even with the best recording conditions it is only possible to follow the process passively without having the possibility to vary any of the parameters which may be of interest or importance.

Starting from these considerations we found it appropriate to elaborate an analog method which would enable us to imitate the strain-release process in the laboratory. A proper analog procedure would not only make it possible to reproduce the features of this process already observed on the macroscopic scale, but also to modify and to predict the process under somewhat changed initial and boundary conditions.

Since the aftershock sequence is understood at present as a not perfectly elastic process, a mathematical treatment meets serious difficulties.

Among different methods, we have chosen the photoelastic determination of the stress field in transparent models of tectonical structures. The photoelastic analog method is used successfully in different branches of technology, but to our knowledge it has not been used hitherto for tectonic processes.

b. Photo-elastic measurement of stress distribution around a  
model fault

We were fortunate in obtaining the expert advice of Dr. R. Hiltcher, Stockholm, who is a well-known authority on the application of photoelastic stress measurements in technology. The Seismological Institute does not have a photoelastic laboratory, but we had the fortunate possibility to

work in the laboratory of the Royal Water Power Board (Statens Vattenfallsverk) in Stockholm.

A series of two-dimensional transparent models of tectonic bodies were analysed with regard to their stress fields when subjected to certain pressures. We started with an infinitesimal slit in a transparent plate subjected to a uniaxial pressure under an angle of  $45^\circ$  with the slit axis.

This model is an improvement if compared with mathematical models solved hitherto, since in our case a shear stress can be transmitted across the slit axis. For the mathematical models the slit boundaries are assumed to be free. Our case with a transmission of shear stress is a better approximation to the real conditions around a fault. The stress field was determined around the infinitesimal slit. However, it was impossible to state if, under loading, the slit was first closed, and then the shear stress transmitted, or if the two sides of the slit were first displaced and then closed. As only the first case resembles the case of strain accumulation around the fault before an earthquake, the uncertainty had to be overcome. For this purpose a model was built which instead of the open slit had an elongated zone of weakness. Several stages of weakness were realized and the stress field determined for each of them. This corresponds better to the increase of the strain in a real fault zone.

The determinations of the stress field yielded some results which could be directly transposed to macroscopic observations made before.

a) In the photoelastic model experiments with improved boundary conditions as compared with earlier mathematical models, the increase of shear stress towards the ends of a fault is confirmed. There is no longer an infinite shear stress at the fault ends.

β) For a model loaded uniaxially an asymmetry between the two fault

ends is observed. The strain-release density for the Desert Hot Springs aftershocks (Richter, Allen and Nordquist 1958) exhibits a similar pattern in relation to the Mission Creek fault, which may be explained by our finding. This would mean that our two-dimensional stress distribution is a good approximation to the stress field around Mission Creek fault, also that the hypocenters do not vary much in depth. Of course, the aftershocks occur in a material with elastic afterworking and the strain-release density map shows a summary effect in time, whereas the photoelastic material used was nearly perfectly elastic.

y) The isochromatics, i.e. the lines of equal shear stress, have a shape resembling the wings of a butterfly at the two ends of the slit or zone of weakness. It is well known from laboratory experiments that fracture will proceed preferably in the direction of the "butterfly's body". This direction depends strongly on the external pressure field. In an investigation of the Mongolian aftershock sequence starting on December 4, 1957, performed under the present Contract, it was found that the aftershocks were distributed along the E-W striking fault of the main shock up to an aftershock on December 3, 1960. With this shock seismic activity started along a fault extending in the SE direction from the eastern end of the old fault, making an angle of  $40^\circ$  with this fault. As explanation for this secondary activity we propose that the primary fault propagated in the direction of the body of the stress "butterfly".

#### c. Further developments

Our experiments are mainly to be considered as a first step in the application of the photoelastic method to tectonical models. We consider the method as capable to serve for the solution of further problems. Of special interest would be the application of the method to time-dependent processes, as the experiments carried out so far have been exclusively concerned with the time-independent static case. This state of equilibrium

rather represents the stress condition before an earthquake takes place. With the inclusion of time-dependent phenomena, it would be possible to simulate the stress variations during an earthquake sequence. This suggestion was also included in our proposal for continued studies, as was the installation of a photoelastic laboratory at our institute.

### 3. Development of a method to measure stress variations in the crust caused by earth tides and other related phenomena

The measurement of stress changes in the earth's crust is a problem of great current interest. Only few facts about the stress distribution within the earth are known from direct measurements.

A cooperation with Prof. N. Hast in Stockholm was anticipated with the purpose to apply to seismological problems a stress-measuring method developed by him. We planned to measure long-period stress changes connected with earth tides, free vibrations of the earth, and perhaps even the continental uplift of Scandinavia, as well as short-period seismic waves. Unfortunately, for reasons beyond our control the cooperation did not develop in the way planned and did not exceed the stage of consultations.

### 4. Application of array-station records to studies of wave propagation and seismicity

#### a. Statement of the problem

Seismic array stations no doubt represent a major advance as far as seismological recording is concerned with very much increased sensitivity. Combined with computer handling of data recorded on magnetic tape, they have increased efficiency in seismic recording to an extent which has not yet been fully utilized in all respects. The present attempt aimed at testing the use of array-station data for the study of two problems: wave propagation up to distances of a few hundred kilometers and

seismicity in a local area. Even if not explicitly included in our Contract, the problems have close connection with our project, for example from the following two points of view:

- 1) The wave propagation studies showed that Sg and Pg have different attenuation, which can probably be explained only by the rheological properties of the material.
- 2) Studies of secular seismicity and related strain-energy release etc will naturally require collection of data over a great many years before a representative sample is obtained. It has often been assumed that a reliable picture of the secular strain-energy release could instead be obtained by accumulating data for a much shorter time but instead going to much lower magnitudes (as is possible by the increased sensitivity of an array station). The results of our studies demonstrate quite definitely that this is not possible, as the large number of very small shocks do not follow the same rules and formulas as the large ones. For example, an equation like (1) found from small shocks, cannot be extrapolated to large shocks.

b. Research on Tonto Forest Seismological Observatory array records

During the stay of Seweryn J. Duda with the Seismological Laboratory in Pasadena, Calif., we got access to the recordings of the Tonto Forest Seismological Observatory (TFSO) in Payson, Arizona. TFSO is one of the most sensitive seismograph stations in continuous operation. The effective increase of the sensitivity of a station entails that besides earthquakes a large number of artificial events is recorded, especially in regions with numerous quarries like Arizona. This raises the problem of distinguishing between earthquakes and explosions in the range of small epicentral distances, up to several degrees.

From the examination of several hundred records, we found that the appearance of an explosion record does not in general allow an immediate separation from an earthquake. We found that the most pronounced

difference between earthquakes and explosions is the ratio of S- to P-wave energy. The nearest recorded explosion was at a distance of 100 km. At this distance the ratio of S- to P-wave energy amounts in average to as much as 5 (for earthquakes 10) and increases up to 10 (for earthquakes 40) at 300 km distance. This allowed us to exclude explosions from the study of the Arizona seismicity.

The S-waves in explosions are unexpectedly strong if compared with P-waves. However, they are weaker in explosions than in earthquakes of comparable magnitude. This is in analogy to surface waves from nuclear explosions, where Rayleigh waves dominate and Love waves are of secondary importance (Toksöz, Harkrider and Ben-Menahem 1964).

The discrimination of explosions and the study of local seismicity require accurate hypocenter determinations. For the epicentral distance and focal-depth determination, local travel-time tables of high precision are needed, giving the travel times even as function of azimuth. The accuracy in azimuth determination of an epicenter from a single array station is limited mainly by the spacing within the array and by the appearance of different phases at different epicentral distances. The azimuth is difficult to determine accurately from a single array station, especially at distances beyond about  $3^{\circ}$ , considering horizontal refraction in the crust and upper mantle. The conditions would certainly be very much improved if two or more array stations are situated at optimum relative distances. On the basis of our measurements we find that a reasonable lower limit of the relative distance between two or more array stations equipped with seismometers like TFSO, is  $3^{\circ}$ : up to that distance the first phases are sharp and the arrival times on different seismometers of the array can be determined with an accuracy of 0.01 sec. The upper limit of the relative distance of two or more array stations depends on the magnitude limit, down to which one wants all events to be recorded within some given area. From the perceptibility of the station we found that

two or more array stations of TFSO-type at a relative distance of 500 km would assure all earthquakes to be recorded down to magnitude +2.0 in the region between the stations.

The application of an array station to regional problems displays both advantages and shortcomings. The superiority of the seismographic array station over conventional stations results from the following factors:

- a) the high sensitivity of the single seismometers;
- б) the possibility to improve the signal-to-noise ratio;
- γ) the regular spacing of seismometers;
- δ) the possibility to process the data automatically, if recorded on magnetic tape;
- ε) the convenience of operating the station within a relatively limited area.

The main shortcoming of the array station if compared with a network of conventional stations, is the limitation in accuracy in spite of the dimensions of the array.

It is essentially impossible to record earthquakes with small magnitudes at distances greater than some critical distance. No increase of the signal-to-noise ratio can improve this. The only possible way to include small local earthquakes seems to be to record them at small epicentral distances.

It may seem impossible to study the attenuation of seismic waves from records of a single station, even an array station, since both the magnitude and the epicentral distance vary from earthquake to earthquake. However, even in this problem the array station records have proved to deliver results comparable to those of a network of conventional stations. The propagation of seismic waves at short epicentral distances turned out to be complicated. The rapid increase of wave periods at distances of 100 km and 325 km cause a sudden increase in the wave

attenuation. This is especially clear for Sg-waves, carrying most of the seismic energy. The knowledge of the attenuation pattern allowed a better estimation of the seismic energy released in small earthquakes.

### References

This list of references contains only papers referred to in the text of this report, but not included under the present Contract. The latter are listed separately in the next section.

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Publications produced under the present Contract

Complete texts of our publications have been given both in appendixes to monthly and semi-annual reports and in the geophysical literature. References are given below to both these places, where our papers have appeared.

- (1) S.J. Duda and M. Báth 1963: Strain release in the circum-Pacific belt: Kern County 1952, Desert Hot Springs 1948, San Francisco 1957, Geophys. Journ., 7, 554-570. Appendix to the Second Semi-Annual

Technical Report (July-Dec., 1962).

- (2) S.J. Duda 1963: Strain release in the circum-Pacific belt:  
Chile 1960, Journ. Geophys. Res., 68, 5531-5544. Appendix to the  
Ninth Monthly Status Report (March, 1963).
- (3) M. Båth and S.J. Duda 1963: Strain release in relation to focal  
depth, Geofisica pura e applicata, 56, 93-100. Appendix to the  
Third Semi-Annual Technical Report (Jan.-June, 1963).
- (4) M. Båth and S.J. Duda 1964: Earthquake volume, fault plane area,  
seismic energy, strain, deformation and related quantities, Annali  
di Geofisica, 17, 353-368. Appendix to the Fourth Semi-Annual  
Technical Report (July-Dec., 1963).
- (5) S.J. Duda 1965: The stress around a fault according to a  
photoelastic model experiment, Geophys. Journ., 9, 399-410.  
Appendix to the Fourth Semi-Annual Technical Report (July-Dec.,  
1963).
- (6) S.J. Duda 1965: Regional seismicity and seismic wave propagation  
from records at the Tonto Forest Seismological Observatory, Payson,  
Arizona, Proc. Roy. Soc., London (in press). Appendix to the Sixth  
Semi-Annual Technical Report (July-Dec., 1964).
- (7) S.J. Duda 1965: Secular seismic energy release in the circum-  
Pacific belt, Tectonophysics, Elsevier, Amsterdam (in press).  
Appendix to the present report.

#### Journeys in connection with the present Contract

The journeys listed below have been undertaken by S.J. Duda,  
whereas M. Båth has only taken part in some of the journeys to  
Stockholm for planning purposes:

- 1) To Stockholm, in 1962 to visit several institutes for the planning  
of collaboration in the more preliminary stage of the work, in 1963  
mainly to the Royal Water Power Board for the photoelastic

investigations.

- 2) To the Seismological Laboratory in Pasadena, Jan.-Sep., 1964, and visits to a number of geophysical institutes in travelling across U.S.
- 3) Central Sweden, Nov. 1964, searching for a suitable location for the possible installation of a strain seismometer.
- 4) Royal Society, London, Jan. 1965, seismological conference, on the invitation of the Royal Society.

### Finance

In this section we give a complete account on income and expenses for the whole period of the Contract. As there are still some income and expenses to come, some of these items will have to be slightly preliminary (this is mentioned in every pertinent case below).

#### Income

Swedish Crowns

1962

June 29, from EOAR, Brussels ..... 11297:00

Aug. 15, from EOAR, Brussels ..... 20560:00

1963

Feb. 15, from EOAR, Brussels ..... 15502:50

Aug. 9, from EOAR, Brussels ..... 10360:00

1964

Feb. 7, from EOAR, Brussels ..... 10360:00

Aug. 25, from EOAR, Brussels ..... 10250:00

1965

Apr. 29, from EOAR, Brussels ..... 10270:00

July - , from EOAR, Brussels (forthcoming) ..... 9859:00

---

Total income ..... 98458:50

#### Expenses

Swedish Crowns

1962

June 28, Mr. S.J. Duda, salary for June, 1962 .... 2000:00

July 27, Mr. S.J. Duda, salary for July, 1962 .... 2000:00

Aug. 30, Mr. S.J. Duda, salary for Aug., 1962 .... 2000:00

Sep. 24, Mr. S.J. Duda, salary for Sep., 1962 .... 2000:00

Oct. 23, Mr. S.J. Duda, salary for Oct., 1962 .... 2000:00

Nov. 5, Mrs. E. Dreimanis, drawing of figures ... 270:00

<u>Expenses</u> (cont.)	Swedish Crowns
1962	
Nov. 26, Lindstahl Bookshop, Stockholm, six books in rheology and related topics .....	394:75
" 27, Mr. S.J. Duda, salary for Nov., 1962 .....	2000:00
Dec. 15, Mrs. E. Dreimanis, drawing of figures ....	235:00
" 18, Mr. S.J. Duda, salary for Dec., 1962 .....	2000:00
" 28, Mrs. E. Dreimanis, drawing of figures ....	40:00
1963	
Jan. 8, Frisk's Photo, Uppsala, photographic work	296:00
" 28, Mr. S.J. Duda, salary for Jan., 1963 .....	2000:00
" 29, Ljuskopieringen, Uppsala, photographic work	237:64
Feb. 26, Mr. S.J. Duda, salary for Feb., 1963 .....	2000:00
" 26, Weidemann Bookshop, Hanover, 2 books .....	136:08
" 26, Lindstahl Bookshop, Stockholm, 1 book ....	113:00
Mar. 6, Heffer & Sons Bookshop, Cambridge, 1 book	78:35
Apr. 1, Mr. S.J. Duda, salary for Mar., 1963 .....	2000:00
" 1, Mrs. E. Dreimanis, drawing of figures ....	700:00
" 25, Mrs. E. Dreimanis, drawing of figures ....	15:00
" 26, Mr. S.J. Duda, salary for Apr., 1963 .....	2000:00
" 26, Helligren & Co., Uppsala, electrostencils .	126:00
May 21, Mr. S.J. Duda, salary for May, 1963 .....	2000:00
June 26, Mr. S.J. Duda, salary for June, 1963 .....	2000:00
" 26, Mrs. E. Dreimanis, drawing of figures ....	80:00
" 26, Ljuskopieringen, Uppsala, photographic work	37:12
July 27, Helligren & Co., Uppsala, electrostencil ..	31:90
" 29, Mr. S.J. Duda, salary for July, 1963 .....	2000:00
" 29, Lindstahl Bookshop, Stockholm, 1 book (photoelasticity) .....	77:55
Aug. 28, Mr. S.J. Duda, salary for Aug., 1963 .....	2000:00

<u>Expenses</u> (cont.)	Swedish Crowns
1963	
Sep. 28, Mr. S.J. Duda, salary for Sep., 1963 .....	2000:00
Oct. 29, Mr. S.J. Duda, salary for Oct., 1963 .....	2000:00
Nov. 28, 300 reprints of Duda's paper on Chile earthquakes, J. Geophys. Res., 68, 5531-5544	1534:47
" 28, Kungl. Statskontoret, Stockholm, computer work for photoelastic measurements .....	45:00
" 28, Mr. S.J. Duda, salary for Nov., 1963 .....	2000:00
Dec. 21, Dr. R. Hiltcher, Stockholm, expenses for photoelastic experiments .....	1014:40
" 21, Mr. S.J. Duda, salary for Dec., 1963 .....	2000:00
" 21, Mr. S.J. Duda, 33 journeys to Stockholm in the interval May 1, 1962-December 31, 1963, 20:00 Cr. per journey .....	660:00
" 21, Mr. S.J. Duda, advance payment for USA- journey .....	2500:00
1964	
Jan. 23, Mr. S.J. Duda, salary for January, 1964 ..	2500:00
" 23, Roy. Astr. Soc., 325 reprints of paper by Duda & Bath .....	274:52
" 23, Lundequist Bookshop, Uppsala, drawing tools	99:46
" 23, Hellgren & Co., Uppsala, electrostencils .	152:15
" 23, Mrs. E. Dreimanis, drawing of figures ....	820:00
Feb. 25, Mr. S.J. Duda, salary for February, 1964 .	2500:00
" 25, Istituto Geofisico Italiano, Milano, 300 reprints of paper "Strain release ...," ...	346:73
Mar. 24, Mr. S.J. Duda, salary for March, 1964 ....	2500:00
" 24, Frisk's Photo, Uppsala, photos of figures for Semi-Annual Report .....	119:00

<u>Expenses</u> (cont.)	Swedish Crowns
1964	
Apr. 17, Mr. S.J. Duda, advance travel expenses ...	1614:25
" 24, Mr. S.J. Duda, salary for April, 1964 ....	2500:00
May 26, Mr. S.J. Duda, salary for May, 1964 .....	2500:00
June 25, Mr. S.J. Duda, salary for June, 1964 .....	2500:00
July 24, Mr. S.J. Duda, salary for July, 1964 .....	2500:00
Aug. 25, Mr. S.J. Duda, salary for Aug., 1964 .....	2500:00
Sep. 1, Mr. S.J. Duda, advance travel grant .....	2571:25
" 30, Mr. S.J. Duda, salary for Sep., 1964,	
= $2/3 \cdot 2500 + 1/3 \cdot 2000$ .....	2335:00
" 30, Mr. S.J. Duda, remaining travel expenses	
incl. per diem costs during 44 travel days	
at \$ 15 per day .....	2018:22
Oct. 27, Mr. S.J. Duda, salary for Oct., 1964 .....	2000:00
Nov. 25, Mr. S.J. Duda, salary for Nov., 1964 .....	2000:00
Dec. 22, Tipografia S. Pio X, Rome, 300 reprints	
Ann. di Geofisica (Bath & Duda) .....	125:97
" 23 Mr. S.J. Duda, salary for Dec., 1964 .....	2000:00
1965	
Feb. 1, Mr. S.J. Duda, salary for Jan., 1965 .....	2000:00
" 1, Mrs. E. Dreimanis, drawing of figures ....	255:00
" 26, Mr. S.J. Duda, salary for Feb., 1965 .....	2000:00
Mar. 26, Mr. S.J. Duda, salary for Mar., 1965 .....	2000:00
Apr. 26, Mr. S.J. Duda, salary for Apr., 1965 .....	2000:00
" 27, Mrs. E. Dreimanis, drawing of figures ....	305:00
May 25, Mr. S.J. Duda, salary for May, 1965 .....	2000:00
" 25, Mrs. E. Dreimanis, drawing of figures ....	265:00
June 3, Lundequist Bookshop, Uppsala, drawing	
materials .....	101:85

Expenses (cont.)

Swedish Crowns

1965

June 3, X-kopia, Uppsala, reproduction of drawings	407:37
" 24, Seismological Institute, expenses for preparation of reports (stencils, paper, etc)	900:34
" 24, X-kopia, Uppsala, electrostencils .....	108:13

Forthcoming expenses:

Reprints of publications (5), (6) and (7), 300 copies of each .....	2217:00
Mr. S.J. Duda, compensation for increased living expenses, 100 Sw.Cr. per month in the interval Oct. 1964 - May 1965 (pending permission from EOAR) .....	800:00

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Total expenses .....	98458:50
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*Markus Båth*

Markus Båth  
Project Scientist

A P P E N D I X

SECULAR SEISMIC ENERGY RELEASE IN THE CIRCUM-PACIFIC BELT

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Uppsala, Sweden

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# SECULAR SEISMIC ENERGY RELEASE IN THE CIRCUM-PACIFIC BELT

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(Received June , 1965)

## SUMMARY

The paper is based on the data of the largest earthquakes in the 68 years from 1897 to 1964, inclusive. The most complete list of pertinent earthquakes ever published was compiled and is attached as an Appendix.

The circum-Pacific seismic belt is divided into eight regions showing different intensities of strain energy release and statistically different b-coefficients in the recurrence diagrams, which relate number of earthquakes to magnitude. The intensities and b-coefficients are correlated with each other, indicating that the b-coefficient depends on the stress pattern. Inferences are drawn as to the generation of aftershock sequences.

The seismic energy release per year has decreased significantly in the time interval investigated in all depth ranges in the circum-Pacific belt and outside of it. However, any extrapolation beyond that time would be speculative.

## INTRODUCTION

Instrumental seismology exists since about 75 years ago. Seismograms of the largest earthquakes are available for the entire time interval, and the coordinates, origin times, focal depths and magnitudes of a considerable number of these earthquakes have been published. With these data as basis several questions concerning the seismic activity during that time can be answered.

This time interval is short in the scale of the history of the earth. However, this is the longest one, for which a quantitative, non-speculative analysis of the seismicity is possible. Speaking

about the seismic activity in this time interval, we shall use the term "secular seismic activity", as done elsewhere in similar cases.

Energetically the seismic activity of the circum-Pacific belt is the most outstanding. In average, only 24% of the earth's total seismic activity, in terms of energy released, occur outside of it. Therefore, any statistical conclusions will be best founded for this belt, and in the following we shall refer only occasionally to the seismic energy release in the non-Pacific regions.

Benioff (1951) investigated the world-wide strain accumulation and release in great earthquakes for the years 1904-1950. He stated that shallow earthquakes of magnitudes 8.0 and greater are not independent of each other. This statement could be confirmed in the present investigation and found to be true for earthquakes with magnitudes down to 7.0.

The following problems are discussed in the present investigation:

1. the intensity of secular seismic energy release, i.e. the seismic energy released per unit time and unit space in different regions of the circum-Pacific belt;
2. the relation between the number of earthquakes and their magnitudes;
3. the pattern of mutual dependence of seismic energy release in different depth ranges, and in time.

## MATERIAL AND ITS SUBDIVISION

### List of earthquakes

Richter's magnitude  $M$  is applied throughout the investigation (Richter, 1958). Only earthquakes with magnitude  $M \geq 7.0$  are used in the following. The considerations are related to the entire

interval of 68 years, from 1897-1964, unless otherwise mentioned.

The earthquake data were first adopted from the following sources:

1. for 1897-1903 from Gutenberg (1956a), with magnitudes given by Richter (1958);
2. for 1904-1952 from Gutenberg and Richter (1954), with magnitude revisions by Richter (1958);
3. for 1953-Sep. 1957 from the Seismological Bulletin, Pasadena, Calif., as compiled and revised by Gutenberg at the end of every year;
4. for Oct. 1957-1963 from the Provisional Readings at Pasadena;
5. for 1964 from the Seismological Bulletin issued at Uppsala.

The earthquakes in 1897-1903 are only incompletely known. The number of earthquakes with magnitude 7.0 and above is complete since 1918. The number is incomplete for magnitudes below 7.9 in 1904-1917 (Gutenberg and Richter, 1954).

In the present study an attempt was made to find earthquakes with magnitude down to 7.0 also for the time interval 1904-1917. For this purpose the records of the Seismological Institute in Uppsala were used. The station at Uppsala started operation on October 8, 1904, after installation of a Wiechert seismograph. The instrument has been in practically continuous operation ever since, and all records are stored at the institute. This provides a unique opportunity to complete the list for the largest earthquakes.

All earthquakes with surface-wave amplitudes indicating a magnitude of 7.0 and above from October 8, 1904, to December 31, 1917, were listed. For this time 146 earthquakes could be added to the 138 reported by Gutenberg and Richter (1954). Data on epicenters of the additional shocks were compiled from various sources:

1. for 1905-1909 from Szirtes (1909, 1910, 1912, 1913);
2. for 1910 from Milne (1913);
3. for 1911 from Watzof (1921);
4. for 1912 from Schneider (1914);
5. for 1913, 1914, 1915 and 1917 from Turner (1917) and the monthly bulletins of the British Association for the Advancement of Science;
6. for 1916 from Turner (1919).

In most cases the epicentres of the additional earthquakes are less accurate. It is impossible to improve the accuracy from records of a single station, and the published P-arrival times display a considerable scatter of residual times. However, in our investigation the earthquakes are classified according to regions of size exceeding the expected error in location. Thus, the inaccuracy will not influence the final results.

The additional earthquakes are assumed to have normal focal depth as evidenced by the records. The magnitudes are based on all appropriate phases (P, PP, S,  $L_{\max}$ ), which could be identified on the Uppsala seismograms. The magnitudes of the new earthquakes are consistent with the most recent determinations by Gutenberg and Richter (1954) and Richter (1958). The procedure of magnitude determination applied is presented by Båth (1954).

It is difficult to estimate how far the additional earthquakes fill the gap in Gutenberg and Richter's (1954) list. Most probably some earthquakes with focal depth greater than normal are still missing, since their identification is difficult from a single station. However, it is our belief, that for the interval 1904-1917 practically all shallow earthquakes are now known with magnitudes 7.0 and above in the distance range up to  $100^{\circ}$  from

Uppsala. This range includes the seismically most active regions in the world.

In the Appendix a collocation of all known earthquakes in the considered magnitude range from 1897 through 1964 is given. This list serves as a basis for our investigation and is the most complete in existence at present. The magnitudes are as consistent as possible.

#### Depth ranges of the earthquake foci

The earthquakes investigated are classified according to their focal depth. The limiting depth between shallow and intermediate shocks is taken at 65 km, as usual. The limiting depth between intermediate and deep earthquakes is taken at 450 km. This is different from what has been used hitherto, but strongly recommended by the results of an investigation of the strain release versus focal depth (Båth and Duda, 1963). The shallow and intermediate earthquakes in the depth range 0-400 km form one unity and the deep earthquakes in the range 475-650 km form another. These results are valid as well for the secular strain energy release versus focal depth. In the present investigation preference is given to the concept of "strain energy release" instead of "strain release" (Båth and Duda, 1964).

Whereas the limit between shallow and intermediate earthquakes is of rather formal significance, the depth between 400 and 475 km, separating intermediate from deep earthquakes, possibly also separates earthquakes with different genesis and focal mechanism.

There is fairly general agreement that shallow and intermediate earthquakes are due to faulting. However, as shown recently by Benioff (1963) for two instances, the strain seismometer recordings of deep-focus earthquakes (focal depth 600+ km) indicated a "source

in the form of a sudden contraction of a volume of rock at the hypocenter such as might result from a sudden change of state".

Comparing Benioff's result with the strain release versus depth curve (Báth and Duda, 1963), a depth limit between 400 and 475 km, say 450 km, between the two ranges is most justified (Table I).

If Benioff's hypothesis is accepted, the term "seismic energy release" will have different meanings for shallow and intermediate earthquakes on one side and for deep earthquakes on the other. In the first case the seismic energy originates from the reduction of a mechanical stress accumulated around a fault; in the second case it originates from the dynamical effect of a change of state of the material, caused by pressure and temperature conditions.

It is obviously true to speak about a "seismic energy release" at any depth range. If the term "strain energy release" is used in relation to shallow and intermediate earthquakes, the term "release of the energy of state" could be used for deep earthquakes.

In this paper the general term "seismic energy release" will be used independently of depth, whereas the term "strain energy release" will be reserved for shallow and intermediate earthquakes.

#### Subdivision of the circum-Pacific belt

For the purpose of the present investigation the circum-Pacific belt is divided into eight regions (Fig. 1), as evidenced by the distribution of shallow earthquakes. A continuous distribution of epicentres along the belt defines a region. A discontinuity or change of trend in the epicentre distribution defines its limits. The shallow shocks in each of the eight regions of the circum-Pacific belt form linear structures, here called arcs (only in its geometrical sense). The lengths of the arcs are given in Table II.

The size of each region is dictated by the number of earthquakes which has to be large enough to allow statistically significant conclusions. Although from the point of view of tectonics the subdivision into eight regions is not unambiguous, from the point of view of circum-Pacific seismicity it appears useful and renders some clear results.

The distribution of epicenters (Appendix) in the circum-Pacific belt is in agreement with earlier findings (Gutenberg and Richter, 1954). On the other hand, it is noteworthy that the epicentres of shallow earthquakes outside the circum-Pacific belt form an apex at about  $50^{\circ}\text{N}$ ,  $100^{\circ}\text{E}$ . From this point two branches emanate, one running southward and merging into the Burma arc, the other running southwestward, meeting the Alpide belt in Pamir as indicated by the shading in Fig. 1. The first branch parallels the northwestern part of the circum-Pacific belt along Japan, Formosa, Philippines, Celebes and Moluccas (Region 4, Fig. 1) but also the Caroline and Mariana Islands (Region 8, Fig. 1). Thus, there are three belts of shallow earthquakes in the northwestern Pacific area, running parallel to the continental border.

#### RECURRENCE DIAGRAMS

The frequency  $n$  of earthquakes in a region, i.e. the number of earthquakes in a certain time interval with magnitude  $M \pm \Delta M$ , was found to be connected with the magnitude  $M$  by the formula:

$$\log n = \alpha - \beta(M-8) \quad (1)$$

(Gutenberg and Richter, 1954). The constants in formula (1) cannot be determined directly, unless the magnitude intervals are chosen great enough to include at least one shock each. As pointed out

by Utsu (1961), it is advisable instead to determine the constants in the relation:

$$\log N = a - bM, \quad (2)$$

where  $N$  denotes the cumulative frequency of earthquakes, i.e. the number of earthquakes per unit time interval with magnitudes down to  $M$ . The constants in the formulae (1) and (2) are related to each other:

$$b = \beta \quad (3)$$

$$a = \alpha + 8b - \log(b \ln 10). \quad (4)$$

In the present paper  $\log$  and  $\ln$  are the logarithms to the base 10 and  $e$ , respectively.

The constant  $a$  is the logarithm of the total number of earthquakes with magnitudes down to zero (supposing relation (2) can be extrapolated so far without a change of the parameters). The constant depends on the length of the unit time interval and the size of the region considered.

The constant  $b$  indicates the relative proportion of earthquakes with high and low magnitudes. Supposing the seismic energy release pattern to be preserved in time and space within a region,  $b$  is independent of the length of time and the size of the region considered, if the number of earthquakes is sufficiently large.

We assume  $a$  and  $b$  to be constant in the magnitude range investigated, and  $b$  not to have changed with time in that range.

An objection against formula (1) and consequently formula (2) was put forward by Tsuboi (1958) when he pointed out that the

coefficients  $a$  and  $b$  in a relation equivalent with (2) are not independent of each other. From the largest earthquakes in Japan he reported a relation in the form:

$$a = 8 b. \quad (5)$$

Really, from our  $a$ - and  $b$ -coefficients in Table II for shallow as well as for shallow plus intermediate earthquakes a similar relation can be derived. In our opinion, however, (5) shows an apparent relation between  $a$  and  $b$ , being only a consequence of the sampling of earthquakes. This is easily seen from Fig. 2.

Let us consider recurrence diagrams for two populations of earthquakes presented in Fig. 2 by solid lines, and the equations:

$$\left. \begin{aligned} \log N &= a - bM \\ \log N' &= a' - bM. \end{aligned} \right\} \quad (6)$$

The diagrams correspond to the magnitude ranges  $M_1-M_2$  and  $M'_1-M'_2$  respectively with  $M'_1 < M'_2 < M_1 < M_2$ . Without loss of generality the  $b$ -coefficients are assumed to be identical. We also assume the total numbers of earthquakes  $N$  and  $N'$  to be equal.  $M_0$  and  $M'_0$  are the corresponding magnitudes if in (6)  $N$  and  $N'$  are put equal to 1. From the geometry of Fig. 2 it is seen immediately, that

$$\left. \begin{aligned} b &= \tan \phi \\ \text{and } M_0 &= \frac{a}{b} \\ M'_0 &= \frac{a'}{b} . \end{aligned} \right\} \quad (7)$$

Comparing this with (5) we see that the factor 8 in (5) depends

primarily on the magnitude range considered. The factor denotes the intercept magnitude for which one earthquake would have been observed, if the extrapolation of the recurrence diagram would be justified beyond the magnitude range, for which it was found. This extrapolation is, however, by no means obvious (Duda, 1965).

In conclusion,  $a$  and  $b$  cannot generally be dependent on each other in the form (5). The relations (5) or (7), as also the factors  $a$  and  $M_0$  depend on the sampling of data, i.e. the magnitude range considered, as well as the number of earthquakes or the length of the time interval under investigation. Therefore, the  $b$ -coefficient deserves a greater attention, since it is independent of the length of time or number of earthquakes, provided the number exceeds some critical value.

The importance of the last condition was pointed out by Tsuboi (1952) who showed the coefficients  $a$  and  $b$  to reach a stationary value not before the laps of a certain time, amounting to about 15 years in Japan, corresponding to a sufficiently great number of earthquakes. An insufficient number of earthquakes causes the  $b$ -coefficient to be small (Tsuboi, 1952).

However, no general criterion is known so far for the number of earthquakes per unit magnitude range in an earthquake sequence, which assures the coefficients to become stationary. Generally, it can be said that the larger the number of earthquakes is, the more reliable are the coefficients determined.

The constants  $a$  and  $b$  were found for seven of the circum-Pacific regions. In Region 8 (Caroline, Mariana Islands) no determination is possible due to the small number of earthquakes. For the same reason no determination is made separately for intermediate earthquakes, nor for deep earthquakes, for which

in addition the magnitude range is very narrow.

It is understood that for the determination of  $a$  and  $b$  only the magnitude range is considered in which the number of earthquakes in all regions may be assumed to be complete. In our case only earthquakes with  $M \geq 7.0$  are used, for which the lists are complete in all regions beginning with the year 1918. Fig. 3 shows the recurrence diagrams for shallow (curve A), and shallow plus intermediate (curve B) earthquakes in the circum-Pacific and non-Pacific regions. In Table II are given the respective  $a$ - and  $b$ -coefficients obtained from a least-square approximation of the empirical curves by equation (2). The rectilinear approximation of the observational data in Fig. 3 is seen to be best for magnitudes between 7.0 and say, 7.8. For higher magnitudes the deviations become greater in general, due to the smaller number of earthquakes in every region.

The curve for Region 3 (Aleutians, Alaska) is better suited for a curvilinear approximation. This may be caused by the superposition of two natural populations of earthquakes. If the component populations have rectilinear recurrence diagrams with different  $b$ -coefficients, the resulting diagram will be curvilinear, as indicated by Tsuboi (1952). This may also arise, if the  $b$ -coefficient in a region changes with time. It is satisfying that only one of our circum-Pacific regions exhibits this inhomogeneity, which does not even influence significantly the  $b$ -coefficient obtained from the rectilinear approximation of the recurrence diagram.

We state immediately that no statistically significant differences exist between the  $b$ -coefficients for the shallow earthquakes on one side and the shallow plus intermediate earthquakes on the other, within each region.

The b-coefficients vary significantly from region to region. The highest value is found for Region 6 (New Hebrides, Solomon Islands, New Guinea), the lowest for Region 3 (Aleutians, Alaska).

A striking difference is revealed between the b-coefficients in Table II and those found for two aftershock sequences in different circum-Pacific regions. For the Kamchatka 1952 aftershock sequence it amounted to 1.5 (Båth and Benioff, 1958), as compared with  $1.01 \pm 0.05$  for Region 4 (Japan, Kurile, Kamchatka) or with an identical value by Tsuboi (1952) for Japanese earthquakes in the magnitude range 6.0-7.7 and the time interval 1931-1950. For the Aleutian Islands 1957 aftershock sequence it was 1.45 (Duda, 1962), as compared with  $0.73 \pm 0.08$  for Region 3 (Aleutian Islands, Alaska). In a third case the difference is not confirmed: for the Chilean 1960 aftershock sequence it was found to be 0.7 (Duda, 1963), as compared with  $0.91 \pm 0.09$  for Region 1 (South America).

Table II also contains the b-coefficients for shallow as well as shallow and intermediate earthquakes outside the circum-Pacific belt (Region 5). Since these earthquakes occurred in a broad variety of tectonic units, the coefficients are only of formal importance.

#### ENERGY OF EARTHQUAKES

Throughout the computations I applied the magnitude-energy conversion formula by Båth (1958), being practically equal to the most recent one published by Gutenberg (1956b), and within error limits independent of focal depth:

$$\log E = 12.24 + 1.44 M \quad E \text{ in ergs} \quad (8)$$

Numbers, magnitudes and energies of earthquakes in different regions and focal depths

Out of a total of 1263 earthquakes in the time interval and magnitude range under investigation (see Appendix), 1004 (79 %) have epicentres in the circum-Pacific belt (Table II).

Of the total seismic energy of  $38.7 \times 10^{25}$  ergs,  $29.5 \times 10^{25}$  ergs (76 %) originated in the circum-Pacific belt.

With the exception of Region 8 (Caroline, Mariana Islands) the number of earthquakes and the strain energy are greater for shallow than for intermediate shocks. These figures are always lowest for deep shocks.

The greatest total number of earthquakes occurred in Region 6 (New Hebrides, Solomon Islands, New Guinea).

The maximum total seismic energy was released in Region 4 (Japan, Kurile, Kamchatka).

The earthquakes with maximum magnitude occur at intermediate depths only in Region 6 (New Hebrides, Solomon Islands, New Guinea) and Region 8 (Caroline, Mariana Islands). In all other regions the maximum magnitude is observed at shallow depths.

If the maximum magnitude in a depth range is assumed to be an evidence of the strength of the material, it may be concluded that the strength generally decreases with depth from shallow to intermediate earthquakes.

As an average for all pertinent regions, the maximum magnitude of deep earthquakes is 1.1 units lower than the maximum magnitude for shallow or intermediate earthquakes (Table II). Thus, a deep earthquake, whatever its genesis is, releases a maximum seismic energy distinctly lower than the greatest earthquake in the other depth ranges.

### Strain energy release in the circum-Pacific regions

The circum-Pacific regions 1-8 differ in size (Fig. 1). To obtain a measure of the intensity of seismic activity it would be advisable to relate the number of earthquakes or the seismic energy to unit length of arc (as defined above), or unit area drawn by the earthquake epicentres, or, even better, to unit volume drawn by the earthquake hypocentres. Because of the uncertainty in the position of the earthquakes, the size of the epicentral area and especially the hypocentral volume would be too inaccurate. On the contrary, the length of arc drawn by the epicentres can be determined fairly accurately, as it is much greater than the uncertainty of a single epicentre determination. Therefore, we relate the seismic energy of shallow earthquakes in the circum-Pacific belt to one degree of arc. This procedure is not possible for shocks in the other depth ranges, since the intermediate and especially the deep earthquakes occur in clusters and the arched structure of epicentre distribution is discontinuous.

The time intervals investigated are practically identical for all regions. Thus, the strain energy released in shallow earthquakes per degree of arc is a measure of intensity, comparable in all regions. From Table II we find the intensity in shallow earthquakes to be highest in the NW part (Region 4) and the SE part (Region 1) of the circum-Pacific belt. Starting with Region 4 and proceeding around the Pacific Ocean in both directions, the intensity decreases from region to region. Thereby Region 8 is neglected, which parallels Region 5 and is energetically unimportant.

This model of circum-Pacific seismicity with the regions of highest intensity or strain energy release in the NW and SE

parts is most probably related to the tectonical movements of the structure. Any model of the circum-Pacific tectonics should include and explain the features of the intensity of strain release.

Fault-plane solutions are known for only a few and mainly the most recent of the earthquakes used in this investigation. Thus, any tectonical model can only be tentative. Nevertheless, the distribution of the intensity of strain release does not offer support for the hypothesis of the relative rotation of the Pacific Ocean bottom and the surrounding continents (Benioff, 1957; St. Amand, 1957).

In Fig. 4A the b-coefficients are presented as function of strain energy release per  $1^\circ$  of arc. The b-coefficients in Region 3 (Aleutian Islands, Alaska) and in Region 7 (New Zealand, Tonga, Kermadec) probably did not reach their stationary values, because of the low number of earthquakes and are therefore neglected here. Then, regions with high strain energy release per  $1^\circ$  of arc tend to have a low b-coefficient, i.e. the proportion of earthquakes with low magnitudes is smaller and conversely, regions with low strain energy release per  $1^\circ$  of arc tend to have a high b-coefficient, i.e. the proportion of earthquakes with low magnitudes is greater. The regions with lowest b-coefficients are situated in the NW and SE parts of the circum-Pacific belt.

Fig. 4B displays the greatest magnitudes in shallow circum-Pacific earthquakes in relation to the strain energy release per  $1^\circ$  of arc. The maximum magnitude in regions with high intensity of strain energy release tends to be greater and conversely, the maximum magnitude in regions with low intensity tends to be

smaller. This tendency fits into a physical model which explains the behaviour of the b-coefficient shown in Fig. 4A, as well as the difference between the "secular" b-coefficient and the b-coefficients in several aftershock sequences. This model will now be presented.

As the maximum magnitude is higher in regions with the greatest strain energy release per  $1^\circ$  of arc (Fig. 4B), the medium seems to be highly stressed. (Only the non-hydrostatic stress is considered.) It may be concluded that a high strain energy release per  $1^\circ$  of arc is accompanied by a high average stress accumulated in the considered region.

A high average stress in a region will result in a small b-coefficient, i.e. a large proportion of strong earthquakes; and vice versa, a low average stress in a region will result in a large b-coefficient, i.e. a large proportion of small earthquakes.

Turning now to the aftershock sequences, we found for the Kamchatka 1952 and the Aleutian Islands 1957 sequences the b-coefficients to be distinctly greater than the secular b-coefficients in the same regions. This implies the aftershocks to occur in a volume with reduced stress, if compared with the average, acting over a longer time interval in the region. This is expected from and well compatible with Benioff's (1951) hypothesis on aftershock generation. According to this, the aftershocks are a manifestation of the elastic afterworking of the material, following the release of the pure elastic deformation in the main shock. As a consequence of the main shock, the stress in the earthquake volume is reduced. However, the aftershock hypocentres were found to draw a volume practically

identical with the earthquake volume of the main shock (Båth and Duda, 1964). In analogy with the behaviour of the secular b-coefficients in the circum-Pacific regions with low average stress, the b-coefficients for aftershocks are expected to be greater than the secular b-coefficients in the corresponding regions, just as found from our comparison.

In course of an aftershock sequence the stress is reduced consecutively. This should cause the b-coefficient to increase with time during the aftershock sequence. For practical reasons it has not been possible to establish this. The reduction of average stress in course of an aftershock sequence is indicated by the general decrease of the aftershock magnitude with time.

#### Seismic energy release per year

With the data given in the Appendix, the seismic energy release as function of time can be determined fairly well for the interval of 68 years from 1897 through 1964. Although some earthquakes are lacking before 1918, and especially before 1904, the incompleteness is only of minor importance for any consideration of the seismic energy release. The lacking earthquakes have magnitudes not much exceeding 7.0 and would contribute only little to the energy released.

Fig. 5ABC shows the histograms of the seismic energy release per year in shallow, intermediate, and deep shocks in all circum-Pacific regions, together with graphs of the corresponding numbers of earthquakes. The histograms for all three depth ranges exhibit a decrease of the yearly seismic energy release, the least-square approximations being:

for shallow shocks:

$$E(t) = [1480 - (0.75 \pm 0.25) t] \cdot 10^{23} \text{ ergs} \quad 1897 \leq t \leq 1964 \quad (9)$$

for intermediate shocks:

$$E(t) = [515 - (0.26 \pm 0.11) t] \cdot 10^{23} \text{ ergs} \quad 1903 \leq t \leq 1964 \quad (10)$$

for deep shocks:

$$E(t) = [30 - (0.015 \pm 0.009) t] \cdot 10^{23} \text{ ergs} \quad 1906 \leq t \leq 1964 \quad (11)$$

The decrease of the yearly seismic energy release in shallow and intermediate earthquakes is not monotonous. Thus, the standard deviations are large. The general trend, however, is statistically significant.

The decrease with time becomes gentler with increasing depth, and is practically unimportant for deep shocks. Here the general trend is strengthened by the evidence from shallow and intermediate earthquakes.

From the histogram for shallow earthquakes (Fig. 5A) it is seen that before 1906 the yearly strain energy release was much above the mean. This was indicated already by Gutenberg and Richter (1954) and Gutenberg (1956a). It followed a period of quietness from 1907 to about 1916.

The histogram for intermediate shocks (Fig. 5B) shows the greatest elevation above the average from about 1906 through 1916. A negative correlation is thus observed between the shallow and intermediate earthquake energy for that particular time interval. The energy decrease in both shallow and intermediate earthquakes, as well as the negative correlation in 1906-1916 indicate a direct or indirect coupling between the strain energy release in the two depth ranges.

The histograms in Fig. 5AB bring up the question of any possible periodicity of strain energy release in different depth ranges. A first look does not promise any periodicity to be found.

Really, autocorrelation of the yearly strain energy release both in shallow and intermediate earthquakes and crosscorrelation of both data sets together gave negative results. The correlation coefficients turn out to be insignificant.

It may be concluded that no statistically significant periodicity or continuous correlation of strain energy release exists in shallow or intermediate earthquakes. This does not influence the previous finding of a distinctly negative correlation between the two depth ranges for the limited interval between 1906 and 1916.

The negative result of the search for a periodicity in the yearly strain energy release in the entire circum-Pacific belt does not exclude the possibility for periodicities on a smaller scale of space and time, or in a larger time interval worldwide.

Fig.5DE presents the histograms of the yearly strain energy release in the non-Pacific regions for shallow and intermediate earthquakes respectively. A least-square solution yields for the shallow earthquakes:

$$E(t) = [570 - (0.29 \pm 0.13) t] \cdot 10^{23} \text{ ergs} \quad 1897 \leq t \leq 1964 \quad (12)$$

Also here a decrease with time is indicated.

For intermediate earthquakes in the non-Pacific regions (Fig.5E) the data are too scanty for a least-square approximation. An approximation shows this summary strain energy release in the first part of the investigated time interval (1903-1933) to be distinctly greater ( $57.61 \cdot 10^{23}$  ergs in 28 earthquakes) than in the second part (1934-1964:  $17.64 \cdot 10^{23}$  ergs in 18 earthquakes).

Thus, the annual seismic energy release in the world shows

a clear indication of decrease in the interval 1897-1964.

In addition to the least-square solutions for the energy variations with time, also arithmetic means of the yearly energies and of the yearly numbers of earthquakes have been computed for intervals for which reliable observations are available. These means are presented in Table III and Fig. 5.

### RESULTS AND CONCLUSIONS

1. For the purpose of the present study a list of earthquakes with magnitude 7.0 and above was compiled for the interval 1897-1964, inclusive. The list, attached as an Appendix, is the most complete one ever published.
2. The number of earthquakes as a function of their magnitude was approximated by the regression formula (2). The formula appears to be useful for the largest earthquakes in seven of the circum-Pacific regions. The regression coefficient  $b$  differs significantly between the regions and varies with some regularity from region to region.
3. The highest intensities of strain energy release are found in the northwestern (Japan, Kurile, Kamchatka) and southwestern (South America) part of the circum-Pacific belt.
4. The intensity of strain energy release varies from region to region, such that regions with low intensity have a large regression coefficient, and vice versa. The intensities of strain energy release and the  $b$ -coefficients in the circum-Pacific regions indicate a symmetry with respect to a great circle crossing the Pacific Ocean in the SE-NW direction.
5. The secular regression coefficients are lower than for some circum-Pacific aftershock sequences. This is in agreement with Benioff's (1951) hypothesis of aftershock generation.

6. The seismic energy release per year in shallow and intermediate earthquakes has decreased significantly in the 68 years since 1897 both in the circum-Pacific and the non-Pacific regions.

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TABLE I. Depth ranges used for the classification of earthquakes

Earthquake group	Depth range	Remarks	References
Shallow	$\leq 65$ km	faulting mechanism	Gutenberg and Richter (1954)
Intermediate	66 km - 450 km		
Deep	451 km - 720 km	earthquake mechanism possibly different from faulting	Båth and Duda, (1963); Benioff (1963)

TABLE 11.

Parameters characterizing the secular seismic activity (the errors given for a and b are standard deviations of single observations). The a and b values are based on the years 1918-1963; the maximum magnitudes and energies on the years given in Table III.

Region	Length of arc deg	Number of earthquakes				a		b		Maximum magnitude			Seismic energy released $10^{23}$ ergs				Strain in shallow earth per $10^{23}$
		total	shallow	intermediate	deep	shallow A in Fig. 3	b	a	b	shallow	intermediate	deep	total	shallow	intermediate	deep	
1. South America	45	123	61	45	17	8.11 $\pm 0.77$	0.91 $\pm 0.09$	9.23 $\pm 0.80$	1.04 $\pm 0.09$	8.9	8.3	7.9	452	387	49	16	8
2. North America	76	108	92	16	0	11.09 $\pm 0.70$	1.33 $\pm 0.08$	11.53 $\pm 0.65$	1.38 $\pm 0.08$	8.6	8.1	-	334	316	18	0	4
3. Aleutians, Alaska	33	73	59	14	0	6.37 $\pm 0.70$	0.73 $\pm 0.08$	6.89 $\pm 0.73$	0.79 $\pm 0.08$	8.7	8.3	-	236	212	24	0	6
4. Japan, Kurile, Kamchatka	36	181	128	45	8	9.05 $\pm 0.50$	1.01 $\pm 0.05$	9.09 $\pm 0.43$	1.01 $\pm 0.05$	8.9	8.7	7.9	713	572	134	7	15
5. New Guinea, Banda Sea, Celebes, Moluccas, Philippines	59	191	147	38	6	11.09 $\pm 0.60$	1.24 $\pm 0.07$	10.46 $\pm 0.32$	1.15 $\pm 0.04$	8.7	8.7	7.3	605	432	171	2	7
6. New Hebrides, Solomon, New Guinea	40	195	127	68	0	11.98 $\pm 0.87$	1.42 $\pm 0.10$	13.12 $\pm 0.84$	1.56 $\pm 0.10$	8.4	8.6	-	281	201	80	0	5

TABLE II cont.

Region	Length of arc deg	Number of earthquakes				a		b		Maximum magnitude			Seismic energy released 10 <sup>23</sup> ergs			Strain in sheath per 10 <sup>23</sup> earthquakes	
		total	shallow	intermediate	deep	shallow	intermediate	shallow	intermediate	deep	total	shallow	intermediate	deep			
7. New Zealand, Tonga, Kermadec	54	103	52	34	17	9.29 +0.51 -0.51	1.10 +0.06 -0.06	9.51 +0.52 -0.52	1.10 +0.06 -0.06	8.7	8.3	7.9	255	197	44	14	3
8. Caroline, Marianas	24	30	13	15	2	-	-	-	-	8.1	8.7	7.3	76	12	63	1	0
Circum-Pacific belt	367	1004	679	275	50	-	-	-	-	8.9	8.7	7.9	2952	2329	583	40	6
Outside of the circum-Pacific belt	-	259	210	46	3	9.65 +0.29 -0.29	1.06 +0.03 -0.03	9.97 +0.34 -0.34	1.10 +0.04 -0.04	8.7	8.3	7.5	922	845	75	2	0
Total	-	1263	889	321	53	-	-	-	-	8.9	8.7	7.9	3874	3174	658	42	6

TABLE III. Annual means of energies and numbers of earthquakes with  $M \geq 7.0$ 

Depth range	Mean seismic energy per year 10 <sup>23</sup> ergs		Mean number of earthquakes per year			
	Interval	circum-Pacific	non-Pacific	Interval	circum-Pacific	non-Pacific
Shallow	1897-1964	34.25	12.43	1905-1964	10.52	3.37
Intermediate	1903-1964	9.40	1.21	1918-1964	4.28	0.52
Deep	1907-1964	0.69	-	1918-1964	0.80	-
Total	1897-1964	-44.34	-13.64	1905-1964	-15.60	-3.89

A P P E N D I X

Latitudes and longitudes are consistently given to  $0.1^{\circ}$ , even if the accuracy is less. The mean error of the magnitude is 0.2-0.3 units. s = shallow depth.

Year	Date	GMT			Lat	Long	Depth	Magnitude
		h	m	s				
					deg	deg	km	
1897	Feb 7	07	36		40.0 N	140.0 E	s	8.3
	19	20	48		38.0 N	142.0 E	s	8.3
	19	23	48		38.0 N	142.0 E	s	7.9
	May 13	12	30		12.0 N	124.0 E	s	7.9
	Jun 12	11	06		26.0 N	91.0 E	s	8.7
	Aug 5	00	12		38.0 N	143.0 E	s	8.7
	15	12	18		18.0 N	120.0 E	s	7.9
	16	07	54		39.0 N	143.0 E	s	7.9
	Sep 20	19	06		6.0 N	122.0 E	s	8.6
	21	05	12		6.0 N	122.0 E	s	8.7
	Oct 18	23	48		12.0 N	126.0 E	s	8.1
	20	14	24		12.0 N	126.0 E	s	7.9
1898	Jan 24	23	30		No information		s	7.9
	Apr 22	23	36		39.0 N	142.0 E	s	8.3
	29	16	18		12.0 N	86.0 W	s	7.9
	Jun 29	18	36		Region 3		s	8.3
	Aug 31	19	54		Non-Pacific Region		s	7.9
	Nov 17	12	48		Region 7		s	7.8
1899	Jan 24	23	43		17.0 N	98.0 W	s	8.4
	Jun 14	11	09		18.0 N	77.0 W	s	7.8
	Jul 14	13	32		Region 2		s	7.8
	Aug 24	15	09		Region 7		s	7.8

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1899	Sep 4	00 22	60.0 N	142.0 W	s	8.2
	10	17 04	60.0 N	140.0 W	s	7.8
	10	21 41	60.0 N	140.0 W	s	8.6
	29	17 03	3.0 S	128.5 E	s	7.8
	Nov 23	09 49	53.0 N	159.0 E	s	7.9
	24	18 42	32.0 N	131.0 E	s	7.8
	24	18 55	32.0 N	131.0 E	s	7.8
1900	Jan 11	09 07	Region 7		s	7.8
	20	06 33 30	20.0 N	105.0 W	s	8.2
	May 16	20 12	20.0 N	105.0 W	s	7.8
	Jun 21	20 52	20.0 N	80.0 W	s	7.9
	Jul 29	06 59	10.0 S	165.0 E	s	8.1
	Oct 7	21 04	4.0 S	140.0 E	s	7.8
	9	12 28	60.0 N	142.0 W	s	8.2
	29	09 11	11.0 N	66.0 W	s	8.4
	Dec 25	05 04	43.0 N	146.0 E	s	7.8
1901	Jan 7	00 29 30	2.0 S	82.0 W	s	7.8
	Apr 5	23 30 45	45.0 N	148.0 E	s	7.9
	Jun 24	07 02 30	27.0 N	130.0 E	s	7.9
	Aug 9	09 23 30	17.0 N	144.0 E	s	7.9
	9	13 01	22.0 S	170.0 E	s	8.4
	9	18 33 45	40.0 N	144.0 E	s	8.2
	Dec 14	22 57 45	14.0 N	122.0 E	s	7.8
	31	09 02 30	52.0 N	177.0 W	s	7.8
1902	Jan 1	05 20 30	55.0 N	165.0 W	s	7.8
	24	23 27	8.0 S	150.0 E	s	7.8

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1902	Feb 9	07 35	20.0 S	174.0 W	s	7.8
	Apr 19	02 23 30	14.0 N	91.0 W	s	8.2
	Aug 22	03 00	40.0 N	77.0 E	s	8.6
	Sep 22	01 46 30	18.0 N	146.0 E	s	8.1
	23	20 18 30	16.0 N	93.0 W	s	8.4
	Dec 12	23 10	29. N	114.0 W	s	7.8
1903	Jan 4	05 07 00	20.0 S	175.0 W	400	8.0
	14	01 47 36	15.0 N	98.0 W	s	8.2
	Feb 1	09 34 30	48.0 N	98.0 W	s	7.8
	27	00 43 18	8.0 S	106.0 E	s	8.1
	May 13	06 34 06	17.0 S	168.0 E	s	7.9
	Jun 2	13 17 00	57.0 N	156.0 W	100	8.3
	Aug 11	04 32 54	36.0 N	23.0 E	100	8.3
	Dec 28	02 56 00	7.0 N	127.0 E	s	7.8
1904	Jan 20	14 52 06	7.0 N	79.0 W	s	7.9
	Jun 7	08 17 54	40.0 N	134.0 E	350	7.9
	25	14 45 36	52.0 N	159.0 E	s	8.3
	25	21 00 30	52.0 N	159.0 E	s	8.1
	27	00 09 00	52.0 N	159.0 E	s	7.9
	Aug 24	20 59 54	30.0 N	130.0 E	s	7.9
	27	21 56 06	64.0 N	151.0 W	s	8.3
	Dec 20	05 44 18	8.5 N	83.0 W	s	8.3
1905	Jan 22	02 43 54	1.0 N	123.0 E	90	8.4
	Feb 14	08 46 36	53.0 N	178.0 W	s	7.9
	17	11 39 26	35.0 N	152.0 E	s	7.3
	Mar 4	16 00 20	4.0 S	149.0 E	s	7.1

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1905	Mar 4	23 17.5	4.0 S	149.0 E	s	7.2
	18	00 58	27.5 S	173.0 W	s	7.5
	22	03 38 45	50.0 N	180.0	s	7.2
	Apr 4	00 50 00	33.0 N	76.0 E	s	8.6
	26	21 43	21.0 S	70.0 W	s	7.0
	May 18	13 45 06	4.0 S	149.0 E	s	7.5
	Jun 2	05 39 42	34.0 N	132.0 E	100	7.9
	14	11 30	30.0 S	159.0 W	s	7.0
	30	17 07	1.0 S	168.0 W	s	7.6
	Jul 6	16 21 00	39.5 N	142.5 E	s	7.9
	9	09 40 24	49.0 N	99.0 E	s	8.4
	11	15 37 30	22.0 N	143.0 E	450	7.25
	23	02 46 12	49.0 N	98.0 E	s	8.7
	Sep 1	02 45 36	45.0 N	143.0 E	230	7.5
	8	01 43 07	39.0 N	16.0 E	s	7.9
	15	06 02 46	53.0 N	164.0 E	s	7.8
	26	01 26 09	29.0 N	74.0 E	s	7.1
	Oct 21	11 01 37	42.0 N	42.0 E	s	7.5
	24	03 46 42	34.0 N	139.0 E	250	7.25
	Nov 8	22 06 12	40.0 N	24.0 E	s	7.8
	Dec 4	12 20 25	38.0 N	37.0 E	s	7.0
	10	12 36 36	50.0 N	180.0	s	7.0
1906	Jan 21	13 49 35	34.0 N	138.0 E	340	8.4
	31	15 36 00	1.0 N	81.5 W	s	8.9
	Feb 19	01 59 33	14.0 S	160.0 E	s	7.2
	Mar 2	06 15 15	43.0 N	80.0 E	s	7.3

Year	Date	GMT			Lat	Long	Depth	Magnitude
		h	m	s				
1906	Mar 16	22	42	40	24.0 N	121.0 E	s	7.1
	Apr 10	21	22	25	19.0 N	138.0 W	s	7.5
	18	13	12	00	38.0 N	123.0 W	s	8.3
	Jun 19	11	22	41	20.0 N	122.0 E	s	7.1
	24	11	17	49	15.0 N	92.0 E	s	7.3
	Aug 17	00	10	42	51.0 N	179.0 E	s	8.3
	17	00	40	00	33.0 S	72.0 W	s	8.6
	26	05	59	31	4.0 S	149.0 E	s	7.4
	30	02	38	34	21.0 S	70.0 W	s	7.2
	31	14	57	30	27.0 N	97.0 E	100	7.0
	Sep 7	18	52.5		34.0 N	141.0 E	s	7.1
	14	16	04	18	7.0 S	149.0 E	s	8.4
	17	08	38		4.0 S	149.0 E	s	7.1
	28	15	24	54	2.0 S	79.0 W	150	7.9
	Oct 2	02	52		4.0 S	149.0 E	s	7.7
	8	04	53	38	53.5 N	154.5 E	200	7.0
	17	09	40		19.0 N	121.0 E	s	7.3
	24	14	42	51	40.0 N	68.0 E	s	7.1
	Nov 14	17	37		25.0 S	172.0 E	s	7.4
	19	07	18	18	22.0 S	109.0 E	s	7.75
	Dec 3	22	59	24	15.0 N	61.0 W	100	7.5
	19	01	14	20	19.0 S	172.0 W	s	7.3
	22	18	21	00	43.5 N	85.0 E	s	8.3
	23	17	22	40	59.0 N	171.0 W	s	7.6
	26	06	53	28	18.0 S	71.0 W	s	7.9
1907	Jan 2	12	56.5		21.1 S	175.1 W	s	7.3

Year	Date	GMT	lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1907	Jan 4	05 19 29	2.0 N	96.3 E	s	7.8
	Feb 3	19 34 57	6.0 S	148.0 E	s	7.2
	Mar 29	20 46 30	3.0 N	122.0 E	500	7.25
	31	22 00 36	18.0 S	177.0 W	400	7.25
	Apr 13	17 57 18	36.5 N	70.5 E	260	7.0
	15	06 08 06	17.0 N	100.0 W	s	8.3
	18	23 52 26	13.6 N	122.9 E	s	7.2
	May 4	06 51	7.5 S	153.7 E	s	7.7
	4	08 36 48	28.0 N	141.0 E	200	7.0
	7	10 16	2.8 S	144.5 E	s	7.0
	25	14 02 08	51.5 N	147.0 E	600	7.9
	Jun 13	09 38 53	39.5 S	73.0 W	s	7.3
	25	17 54 36	1.0 N	127.0 E	200	7.9
	Jul 9	19 54 50	14.0 N	123.0 E	s	7.0
	20	13 38 34	7.1 N	125.6 E	s	7.1
	Aug 17	17 27 54	52.0 N	157.0 E	120	7.25
	Sep 2	16 01 30	52.0 N	173.0 E	s	7.75
	Oct 11	14 28	17.0 S	161.0 E	s	7.3
	16	14 57	27.4 N	112.3 W	s	7.7
	21	04 23 36	38.0 N	69.0 E	s	8.1
	Nov 21	20 03 35	5.9 N	95.3 E	s	7.4
	Dec 15	17 35	3.1 S	142.5 E	s	7.4
	30	05 26 59	12.1 N	86.3 W	s	7.2
1908	Jan 11	03 35	23.0 N	121.0 E	s	7.3
	15	12 56	36.0 N	142.0 E	s	7.3
	Feb 9	18 13	26.0 N	100.0 E	s	7.3

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1908	Mar 5	02 16	9.0 N	126.0 E	s	7.5
	26	23 03 30	18.0 N	99.0 W	80	8.1
	27	03 45.5	17.0 N	101.0 W	s	7.5
	May 5	06 16	3.0 N	123.0 E	s	7.5
	Aug 17	10 32	60.0 S	40.0 W	s	7.4
	20	09 53	32.0 N	89.0 E	s	7.0
	Oct 23	20 14 06	36.5 N	70.5 E	220	7.0
	24	21 16 36	36.5 N	70.5 E	220	7.0
	Nov 2	05 16	2.0 S	97.0 E	s	7.3
	6	07 12	30.0 N	160.0 E	s	7.6
	Dec 12	12 08	14.0 S	78.0 W	s	8.2
1909	Jan 23	02 48	33.0 N	50.0 E	s	7.7
	Feb 22	09 21 42	18.0 S	179.0 W	550	7.9
	26	16 42	5.0 N	95.0 W	s	7.1
	Mar 12	23 14	32.0 N	140.0 E	s	7.1
	13	14 29 00	31.5 N	142.5 E	80	8.3
	17	22 53	2.0 S	121.0 E	s	7.1
	Apr 10	05 23	9.0 S	180.0	s	7.3
	10	18 43	80.0 N	140.0 E	s	7.0
	10	19 36	45.0 N	165.0 E	s	7.8
	14	19 53 42	24.0 N	123.0 E	80	7.3
	25	22 36 00	4.0 N	127.0 E	100	7.0
	27	12 44	0.0	147.0 E	s	7.3
	29	22 34	27.0 S	63.0 E	(s)	7.0
	May 17	08 02 54	20.0 S	64.0 W	250	7.1
	30	21 01 18	8.0 S	131.0 E	100	7.2

Year	Date	GMT			Lat	Long	Depth	Magnitude
		h	m	s	deg	deg	km	
1909	Jun 3	18	44		2.0 S	102.0 E	s	7.7
	8	05	46		25.0 S	73.0 W	s	7.6
	Jul 7	21	37	50	36.5 N	70.5 E	230	8.1
	7	21	39	05	36.5 N	70.5 E	s	8.0
	30	10	51	54	17.0 N	100.5 W	s	7.75
	31	19	18		13.0 N	101.0 W	s	7.3
	Aug 16	06	58		10.0 N	84.0 W	s	7.1
	18	00	39	30	22.0 S	172.0 E	100	7.25
	Sep 8	16	49	48	52.5 N	169.0 W	90	7.4
	Oct 20	23	42		29.0 N	68.0 E	s	7.0
	31	10	18		8.0 N	105.0 W	s	7.4
	Nov 10	06	13	30	32.0 N	131.0 E	190	7.9
	21	07	36		25.0 N	122.0 E	s	7.3
	Dec 9	15	33		8.0 S	161.0 E	s	7.2
	9	23	23		10.0 S	165.0 E	s	7.7
1910	Jan 1	11	02		24.0 N	90.0 W	s	7.5
	22	06	48		67.0 N	19.0 W	s	7.2
	23	18	49	42	12.0 N	60.5 W	100	7.2
	Feb 4	14	00		17.0 S	166.0 E	s	7.3
	12	18	10	06	32.5 N	138.0 E	350	7.4
	18	05	09	18	36.0 N	24.5 E	150	7.0
	Mar 30	16	55	48	21.0 S	170.0 E	80	7.25
	Apr 12	00	22	13	25.5 N	122.5 E	200	8.3
	20	22	22	00	20.0 S	177.0 W	330	7.0
	May 1	18	30	36	20.0 S	169.0 E	80	7.1
	22	06	25		42.0 N	145.0 E	s	7.5

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1910	May 31	04 54	10.0 N	105.0 W	s	7.2
	Jun 1	05 55 30	20.0 S	169.0 E	80	7.5
	1	06 48 18	20.0 S	169.0 E	80	7.25
	16	06 30 42	19.0 S	169.5 E	100	8.6
	Aug 21	05 38 36	17.0 S	179.0 W	600	7.25
	Sep 1	00 45	21.0 N	122.0 E	s	7.1
	1	14 20	24.0 N	122.0 E	s	7.3
	7	07 11 18	6.0 S	151.0 E	80	7.25
	9	01 11	45.0 N	170.0 W	s	7.3
	24	03 23	2.0 S	102.0 W	s	7.3
	Oct 4	23 00 06	22.0 S	69.0 W	120	7.25
	Nov 9	06 02 00	16.0 S	166.0 E	70	7.9
	10	12 19 54	14.0 S	166.5 E	90	7.2
	14	07 53	21.0 N	120.0 E	s	7.0
	15	14 18	62.0 S	16.0 W	s	7.4
	26	04 39	8.0 S	167.0 E	s	8.0
	Dec 13	11 34	9.0 S	33.0 E	s	7.1
	14	20 46 12	21.0 S	178.0 W	600	7.0
	16	14 45	5.0 N	125.0 E	s	7.2
1911	Jan 1	10 17 43	38.0 N	67.0 E	s	7.2
	3	23 25 45	43.5 N	77.5 E	s	8.7
	Feb 18	18 41 03	40.0 N	73.0 E	s	7.75
	23	11 14 12	27.0 N	128.0 E	s	7.1
	Apr 4	15 43 54	36.5 N	25.5 E	140	7.0
	10	18 42 24	9.0 N	74.0 W	100	7.2
	28	09 52 54	0.0	71.0 W	600	7.1

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1911	May 4	23 36 54	51.0 N	157.0 E	240	7.6
	Jun 7	11 02 42	17.5 N	102.5 W	s	7.9
	15	14 26 00	29.0 N	129.0 E	160	8.7
	Jul 4	13 33 26	36.0 N	70.5 E	190	7.6
	5	18 40 06	7.5 S	117.5 E	370	7.0
	12	04 07 36	9.0 N	126.0 E	s	7.75
	Aug 16	22 41 18	7.0 N	137.0 E	s	8.1
	21	16 28 55	21.0 S	176.0 W	300	7.3
	Sep 6	00 54 18	46.0 N	143.0 E	350	7.3
	Oct 20	17 44 00	12.5 S	166.0 E	160	7.1
	Nov 22	23 05 24	15.0 S	169.0 E	200	7.25
1912	Jan 31	20 11 48	61.0 N	147.5 W	80	7.25
	Mar 25	04 49 30	18.0 S	169.0 E	240	7.0
	May 6	18 59 43	63.5 N	23.0 W	s	7.5
	23	02 24 06	21.0 N	97.0 E	s	7.9
	Jul 7	07 57 35	63.3 N	157.4 W	(s)	7.1
	Aug 6	21 11	14.0 S	167.0 E	260	7.2
	9	01 29 00	40.5 N	27.0 E	s	7.75
	Sep 1	04 10 00	4.5 S	155.0 E	430	7.0
	29	20 51	16.6 N	138.6 E	s	7.6
	Oct 18	11 48	54.6 N	179.2 E	s	7.1
	26	09 00 36	14.0 N	146.0 E	130	7.0
	31	17 22	11.2 N	128.8 E	s	7.4
	Nov 7	07 40 24	57.5 N	155.0 W	90	7.5
	19	13 55 00	19.0 N	100.0 W	80	7.0
	Dec 5	12 27 36	57.5 N	154.0 W	90	7.0

Year	Date	GMT			Lat	Long	Depth	Magnitude
		h	m	s	deg	deg	km	
1912	Dec 7	22	46	50	29.0 S	62.5 W	620	7.5
	9	08	32	29	19.0 N	85.0 W	s	7.3
1913	Jan 11	13	17	02	3.0 N	122.0 E	s	7.3
	19	17	05	15	1.0 N	88.0 E	s	7.4
	19	23	47	55	46.0 N	152.0 E	150	7.0
	Feb 20	08	58	48	41.0 N	144.0 E	s	7.1
	Mar 6	11	03	42	30.0 N	83.0 E	s	7.3
	14	08	45	00	4.5 N	126.5 E	s	8.3
	23	20	47	18	24.0 N	142.0 E	80	7.0
	31	03	40	48	49.5 N	178.0 W	s	7.3
	Apr 25	17	56	08	9.5 N	128.8 E	s	7.7
	May 8	18	35	24	17.0 S	174.5 W	200	7.0
	18	02	08	53	14.5 N	145.5 E	s	7.1
	30	11	46	46	5.0 S	154.0 E	s	7.5
	Jun 22	13	49	52	48.0 N	178.0 W	s	7.2
	26	04	57	01	22.5 S	173.5 W	s	8.2
	Aug 1	17	10	57	47.5 N	155.5 E	s	7.7
	6	22	14	24	17.0 S	74.0 W	s	7.9
	13	04	25	42	5.5 S	105.0 E	75	7.2
	Oct 14	08	08	48	19.5 S	169.0 E	230	8.1
	Nov 10	21	12	30	18.0 S	169.0 E	80	7.5
	15	05	27	06	23.0 S	171.0 E	150	7.0
	Dec 21	15	37	48	24.5 N	102.0 E	s	7.2
1914	Jan 20	12	00	13	52.9 N	159.6 E	s	7.2
	30	03	35	50	34.1 S	66.0 W	s	8.2
	Feb 6	11	42	18	29.5 N	65.0 E	100	7.0

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1914	Feb 26	04 58 12	18.0 S	67.0 W	130	7.2
	Mar 14	20 00 06	39.2 N	139.8 E	s	7.2
	30	00 41 18	17.0 N	92.0 W	130	7.5
	May 26	14 22 42	2.0 S	137.0 N	s	7.9
	28	03 23 54	9.0 N	78.0 W	70	7.2
	Jun 25	19 06 44	4.5 S	99.0 E	s	8.1
	Jul 4	23 38 54	5.5 S	129.0 E	200	7.0
	Aug 4	22 41 15	40.5 N	90.5 E	s	7.3
	6	04 10 42	6.0 S	123.0 E	600	7.0
	Oct 3	17 22 12	16.0 N	61.0 S	100	7.4
	3	22 06 34	37.5 N	32.5 E	s	7.7
	11	16 17 06	12.0 N	94.0 E	80	7.2
	23	06 18 34	6.0 N	132.5 E	s	7.9
	Nov 22	08 14 18	39.0 S	176.0 E	100	7.0
	24	11 53 30	22.0 N	143.0 E	110	8.7
1915	Jan 5	14 33 15	15.0 S	168.0 E	200	7.25
	5	23 26 42	25.0 N	123.0 E	160	7.25
	13	06 52 38	42.0 N	13.5 E	s	7.5
	Feb 25	20 36 12	20.0 S	180.0	600	7.25
	28	18 59 05	23.6 N	123.5 E	s	7.7
	Mar 8	15 29 43	39.0 N	142.0 E	s	7.0
	17	18 45 00	42.0 N	142.0 E	100	7.25
	Apr 23	15 29 18	8.0 S	68.0 W	650	7.25
	May 1	05 00 00	47.0 N	155.0 E	s	8.1
	Jun 6	21 29 37	18.5 S	68.5 W	160	7.6
	Jul 31	01 31 24	54.0 N	162.0 E	s	7.75

Year	Date	GMT			Lat	Long	Depth	Magnitude
		h	m	s				
1915	Sep 7	01	20	48	14.0 N	89.0 W	80	7.9
	Oct 3	06	52	48	40.5 N	117.5 W	s	7.75
	8	15	36	03	33.5 N	138.0 E	170	7.0
	Nov 1	07	23	43	38.0 N	144.0 E	s	7.8
	21	00	13	32	32.0 N	119.0 W	s	7.0
	Dec 3	02	39	19	29.5 N	91.5 E	s	7.1
1916	Jan 1	13	20	36	4.0 S	154.0 E	s	7.9
	13	06	18	16	2.0 S	137.0 E	s	8.1
	13	08	20	48	3.0 S	135.5 E	s	8.1
	24	06	55	07	41.0 N	37.0 E	s	7.8
	Feb 1	07	36	22	29.5 N	131.5 E	s	8.0
	6	21	51	19	48.5 N	178.5 E	s	7.7
	27	20	20	36	10.5 N	91.0 W	s	7.6
	Mar 25	23	52	17	24.0 N	124.0 E	s	7.4
	Apr 18	04	01	48	53.3 N	170.0 W	170	7.5
	21	11	31	45	34.0 N	139.5 E	s	7.8
	24	04	26	42	18.5 N	68.0 W	80	7.2
	24	08	02	08	10.0 N	82.0 W	s	7.6
	Jun 2	13	59	24	17.5 N	95.0 W	150	7.1
	21	21	32	30	28.5 S	63.0 W	600	7.5
	Jul 8	09	34	30	16.0 S	180.0	600	7.0
	27	11	52	42	4.0 N	96.5 E	100	7.0
	Aug 3	01	30	02	4.0 S	144.5 E	s	7.5
	25	09	44	42	21.0 S	68.0 W	180	7.5
	28	06	39	29	30.0 N	81.0 E	s	7.7
	Sep 11	06	30	36	9.0 S	113.0 E	100	7.25

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1916	Sep 15	07 01 18	34.5 N	141.0 E	100	7.25
	Oct 31	15 30 33	46.5 N	160.0 E	s	7.7
1917	Jan 30	02 45 36	56.5 N	163.0 E	s	8.1
	Feb 20	19 29 32	19.0 N	80.0 W	s	7.1
	Mar 15	00 14 06	38.5 N	144.5 E	s	7.1
	Apr 21	00 49 49	37.0 N	70.5 E	220	7.0
	May 1	18 26 30	29.0 S	177.0 W	60	8.6
	31	08 47 20	54.5 N	160.0 W	s	7.8
	Jun 26	05 49 42	15.5 S	173.0 W	s	8.7
	Jul 4	00 38 20	25.0 N	123.0 E	s	7.7
	4	05 36 30	25.0 N	123.0 E	s	7.2
	29	14 32 15	41.0 N	144.0 E	s	7.0
	30	23 54 05	29.0 N	104.0 E	s	7.5
	31	03 23 10	42.5 N	131.0 E	460	7.5
	Aug 30	04 07 15	7.5 S	128.0 E	100	7.75
	31	11 36 18	5.0 N	75.0 W	s	7.2
	Nov 4	12 03 30	4.8 N	96.8 E	s	7.1
	16	03 19 25	29.0 S	178.0 W	s	7.8
	Dec 29	22 50 20	15.0 N	97.0 W	s	7.7
1918	Jan 30	21 18 33	45.5 N	135.0 E	330	7.7
	Feb 7	05 20 30	6.5 N	126.5 E	120	7.5
	13	06 07 13	24.0 N	117.0 E	s	7.3
	Apr 10	02 03 54	43.5 N	130.5 E	570	7.2
	May 20	14 36 00	7.5 N	36.0 W	s	7.4
	20	17 55 10	28.5 S	71.5 W	80	7.9
	22	06 31 27	17.0 S	177.5 W	380	7.0

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1918	May 25	19 29 20	30.5 S	92.5 W	60	7.0
	Jul 3	06 52 05	3.5 S	142.5 E	s	7.5
	8	10 22 07	24.5 N	91.0 E	s	7.6
	Aug 15	12 18 12	5.5 N	123.0 E	s	8.3
	15	17 30 11	5.5 N	126.0 E	s	7.0
	Sep 7	17 16 13	45.5 N	151.5 E	s	8.3
	Oct 11	14 14 30	18.5 N	67.5 W	s	7.5
	14	12 00 30	19.0 S	174.0 W	130	7.0
	27	17 06 40	2.0 S	148.0 E	50	7.4
	Nov 8	04 38 00	44.5 N	151.5 E	s	7.9
	18	18 41 55	7.0 S	129.0 E	190	8.1
	23	22 57 55	7.0 S	129.0 E	190	7.25
	Dec 4	11 47 48	26.0 S	71.0 W	s	7.75
	6	08 41 05	49.8 N	126.5 W	s	7.0
1919	Jan 1	01 33 42	8.0 N	126.0 E	s	7.4
	1	02 59 57	19.5 S	176.5 W	180	8.3
	Mar 2	03 26 50	41.0 S	73.5 W	40	7.2
	2	11 45 17	41.0 S	73.5 W	40	7.3
	Apr 17	11 22 05	29.5 S	178.0 W	s	7.0
	17	20 53 03	14.5 N	91.8 W	s	7.0
	30	07 17 05	19.0 S	172.5 W	s	8.4
	May 3	00 52 00	40.5 N	145.5 E	s	7.6
	6	19 41 12	5.0 S	154.0 E	s	8.1
	Jun 1	06 51 20	26.5 N	125.0 E	200	7.0
	Aug 18	16 55 25	20.5 S	178.5 W	300	7.2
	29	05 43 54	2.5 S	127.0 E	s	7.0

Year	Date	GMT			Lat	Long	Depth	Magnitude
		h	m	s				
					deg	deg	km	
1919	Aug 31	17	20	46	16.0 S	169.0 E	180	7.25
	Nov 20	14	11	43	13.0 S	167.0 E	210	7.0
	Dec 20	20	37	27	22.0 N	122.0 E	s	7.0
1920	Feb 2	11	22	18	4.0 S	152.5 E	s	7.7
	22	17	35	50	47.5 N	146.0 E	340	7.0
	Mar 20	18	31	25	35.0 S	110.0 W	s	7.0
	Jun 5	04	21	28	23.5 N	122.0 E	s	8.3
	Sep 20	14	39	00	20.0 S	168.0 E	e	8.3
	Oct 18	08	11	35	45.0 N	150.5 E	50	7.2
	Dec 10	04	25	40	39.0 S	73.0 W	s	7.4
	16	12	05	43	36.0 N	105.0 E	s	8.6
1921	Feb 4	08	22	44	15.0 N	91.0 W	120	7.5
	27	18	23	54	18.5 S	173.0 W	s	7.2
	Mar 28	07	49	22	12.5 N	87.5 W	s	7.3
	Jul 4	14	18	20	25.5 N	141.5 E	200	7.2
	Sep 11	04	01	38	11.0 S	111.0 E	s	7.5
	13	02	36	54	55.0 S	29.0 W	s	7.2
	Oct 15	04	58	12	13.5 S	166.0 E	40	7.0
	20	06	03	24	18.5 S	68.0 W	120	7.0
	Nov 11	18	36	08	8.0 N	127.0 E	s	7.5
	15	20	36	38	36.5 N	70.5 E	215	8.1
	Dec 18	15	29	35	2.5 S	71.0 W	650	7.9
1922	Jan 6	14	11	02	16.5 S	73.0 W	s	7.2
	9	05	09	34	24.0 N	46.0 W	s	7.1
	17	03	50	33	2.5 S	71.0 W	650	7.6
	31	13	17	22	41.0 N	125.5 W	s	7.3

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1922	Mar 4	13 07 38	52.5 N	157.0 E	220	7.0
	28	03 57 54	21.0 S	68.0 W	90	7.2
	Sep 1	19 16 06	24.5 N	122.0 E	s	7.6
	14	19 31 39	24.5 N	121.5 E	s	7.2
	Oct 11	14 49 50	16.0 S	72.5 W	50	7.4
	24	21 21 06	47.0 N	151.5 E	80	7.4
	Nov 7	23 00 09	28.0 S	72.0 W	s	7.0
	11	04 32 36	28.5 S	70.0 W	s	8.4
	Dec 6	13 55 36	36.5 N	70.5 E	230	7.5
	31	07 19 59	45.5 N	151.3 E	s	7.0
1923	Jan 22	09 04 18	40.5 N	124.5 W	s	7.2
	Feb 1	19 24 58	21.0 S	169.5 E	50	7.0
	2	05 07 38	53.5 N	162.0 E	s	7.2
	3	16 01 41	54.0 N	161.0 E	s	8.4
	24	07 34 36	56.0 N	162.5 E	s	7.4
	Mar 2	16 48 52	6.5 N	124.0 E	s	7.2
	16	22 01 38	6.0 N	127.0 E	s	7.0
	24	12 40 06	31.5 N	101.0 E	s	7.3
	Apr 13	15 31 02	56.5 N	162.5 E	s	7.2
	19	03 09 08	2.5 N	117.5 E	s	7.0
	May 4	16 26 39	55.5 N	156.5 W	s	7.1
	4	22 26 45	28.8 S	71.8 W	60	7.0
	Jun 1	17 24 42	35.8 N	141.8 E	s	7.2
	22	06 44 33	22.8 N	98.8 E	s	7.3
	Jul 13	11 13 34	31.0 N	130.5 E	s	7.2
	Sep 1	02 58 36	35.5 N	139.5 E	s	8.3

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1923	Sep 2	02 46 40	35.0 N	139.5 E	s	7.7
	2	22 38 12	16.0 S	68.5 W	150	7.0
	9	22 03 43	25.3 N	91.0 E	s	7.1
	Oct 7	03 29 34	1.8 S	128.8 E	s	7.5
	Nov 2	21 08 06	4.5 S	151.5 E	50	7.2
	4	00 04 30	5.0 S	152.0 E	s	7.2
	5	21 27 53	29.3 N	130.0 E	s	7.2
1924	Jan 16	21 38 00	21.0 S	176.0 W	350	7.0
	21	01 52 54	55.0 N	156.5 E	340	7.0
	Mar 4	10 07 42	9.8 N	84.0 W	s	7.0
	15	10 31 22	49.0 N	142.5 E	s	7.0
	Apr 14	16 20 23	6.5 N	126.5 E	s	8.3
	May 4	16 51 43	21.0 S	178.0 W	560	7.3
	28	09 51 59	48.0 N	146.0 E	500	7.0
	Jun 26	01 37 34	56.0 S	157.5 E	s	8.3
	30	15 44 25	45.0 N	147.5 E	120	7.3
	Jul 3	04 40 06	36.0 N	84.0 E	s	7.2
	11	19 44 40	36.5 N	84.0 E	s	7.2
	24	04 55 17	49.5 S	159.0 E	50	7.5
	Aug 14	18 02 37	36.0 N	142.0 E	s	7.0
	30	03 04 57	8.5 N	126.5 E	s	7.3
	Oct 13	16 17 45	36.0 N	70.5 E	220	7.3
	Dec 27	11 22 05	45.0 N	146.0 E	150	7.3
	28	22 54 56	43.3 N	147.0 E	s	7.0
1925	Jan 18	12 05 54	47.5 N	153.5 E	s	7.3
	Mar 1	02 19 18	48.3 N	70.8 W	s	7.0

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1925	Mar 16	14 42 12	25.5 N	100.3 E	s	7.1
	22	08 41 55	18.5 S	168.5 E	50	7.6
	29	21 12 37	8.0 N	78.0 W	60	7.1
	Apr 11	10 42 02	31.0 S	59.0 E	s	7.0
	16	19 52 35	22.0 N	121.0 E	s	7.1
	May 3	17 21 45	1.5 N	127.0 E	s	7.1
	3	22 59 04	34.0 S	58.0 E	s	7.0
	15	11 56 57	26.0 S	71.5 W	50	7.1
	Jun 3	04 33 55	1.5 N	126.5 E	s	7.1
	9	13 40 41	3.0 S	140.0 E	s	7.0
	Aug 19	12 07 27	55.3 N	168.0 E	s	7.2
	Oct 13	17 40 34	11.0 N	42.0 W	s	7.5
	Nov 10	13 50 36	1.0 S	129.5 E	s	7.4
	13	12 14 45	13.0 N	125.0 E	s	7.3
	16	11 54 54	18.0 N	107.0 W	s	7.0
1926	Jan 25	00 36 18	9.0 S	158.0 E	s	7.4
	Feb 8	15 17 49	13.0 N	89.0 W	s	7.1
	Mar 21	14 19 12	61.0 S	25.0 W	s	7.1
	27	10 48 30	9.0 S	157.0 E	s	7.2
	Apr 12	08 32 28	10.0 S	161.0 E	s	7.5
	28	11 13 50	24.0 S	69.0 W	180	7.0
	Jun 3	04 46 56	15.0 S	168.5 E	60	7.1
	26	19 46 34	36.5 N	27.5 E	100	8.3
	29	14 27 06	27.0 N	127.0 E	130	7.5
	Jul 10	10 51 10	1.0 N	126.0 E	40	7.0
	Aug 25	05 44 40	23.0 S	172.0 E	50	7.0

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1926	Aug 30	11 38 12	36.8 N	23.3 E	100	7.0
	Sep 2	01 21 52	33.5 S	59.0 E	s	7.0
	10	10 34 29	9.0 S	111.0 E	80	7.0
	16	17 59 12	11.5 S	160.0 E	50	7.1
	Oct 3	19 38 01	49.0 S	161.0 E	60	7.9
	13	19 08 07	52.0 N	176.0 W	s	7.1
	26	13 44 41	3.5 S	138.5 E	s	7.9
	Nov 5	07 55 38	12.3 N	85.8 W	135	7.0
1927	Jan 24	01 05 43	15.5 S	167.5 E	s	7.1
	Feb 16	01 35 20	47.0 N	153.5 E	s	7.0
	Mar 3	01 05 09	6.0 S	122.0 E	s	7.0
	7	09 27 36	35.8 N	134.8 E	s	7.9
	Apr 1	19 06 09	20.0 S	177.5 W	400	7.1
	14	06 23 34	32.0 S	69.5 W	110	7.1
	May 22	22 32 42	36.8 N	102.0 E	s	8.3
	Jun 3	07 12 11	7.0 S	131.0 E	150	7.4
	Aug 5	21 12 55	37.5 N	142.5 E	s	7.1
	10	11 36 15	1.0 S	131.0 E	s	7.1
	20	23 54 25	5.0 N	82.5 W	s	7.0
	Oct 24	15 59 55	57.5 N	137.0 W	s	7.1
	Nov 4	13 50 45	34.5 N	121.5 W	s	7.3
	16	21 10 09	6.5 N	126.0 E	50	7.0
	21	23 12 25	44.5 S	73.0 W	s	7.1
	Dec 28	18 20 23	55.0 N	161.0 E	s	7.3
1928	Jan 6	19 31 58	0.5 N	36.5 E	s	7.0

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1928	Mar 9	18 05 27	2.5 S	88.5 E	s	8.1
	13	18 31 52	5.5 S	153.0 E	100	7.0
	16	05 01 02	22.0 S	170.5 E	s	7.5
	22	04 17 00	16.0 N	96.0 W	s	7.5
	29	05 06 03	31.7 N	138.2 E	410	7.1
	May 14	22 14 46	5.0 S	78.0 W	s	7.3
	27	09 50 26	40.0 N	142.5 E	s	7.0
	Jun 15	06 12 36	12.5 N	121.5 E	s	7.0
	17	03 19 27	16.3 N	98.0 W	s	7.9
	21	16 27 13	60.0 N	146.5 W	s	7.0
	29	22 49 38	15.0 S	170.5 E	s	7.1
	Jul 18	19 05 00	5.5 S	79.0 W	s	7.0
	Aug 4	18 26 16	16.0 N	97.0 W	s	7.4
	24	21 43 30	15.0 S	168.0 E	220	7.0
	Oct 9	03 01 08	16.0 N	97.0 W	s	7.6
	Nov 20	20 35 07	22.5 S	70.5 W	s	7.1
	Dec 1	04 06 10	35.0 S	72.0 W	s	8.3
	19	11 37 10	7.0 N	124.0 E	s	7.3
1929	Jan 13	00 03 12	49.8 N	154.8 E	140	7.7
	Feb 1	17 14 26	36.5 N	70.5 E	220	7.1
	2	00 00 19	1.5 S	21.0 W	s	7.1
	22	20 41 46	11.0 N	42.0 W	s	7.2
	Mar 7	01 34 39	51.0 N	170.0 W	60	8.6
	May 1	15 37 30	38.0 N	58.0 E	s	7.1
	26	22 39 54	51.0 N	131.0 W	r	7.0
	Jun 2	21 38 34	34.5 N	137.3 E	360	7.1

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1929	Jun 4	15 15 58	6.5 N	124.5 E	380	7.0
	13	09 24 34	8.5 N	127.0 E	s	7.2
	16	22 47 32	41.8 S	172.3 E	s	7.6
	27	12 47 05	54.0 S	29.5 W	s	8.3
	Jul 5	14 19 02	51.0 N	178.0 W	s	7.0
	7	21 23 12	52.0 N	178.0 W	s	7.3
	Oct 19	10 12 52	23.0 S	69.0 W	100	7.5
	Nov 15	18 50 33	7.5 N	142.5 E	s	7.2
	18	20 31 58	44.0 N	16.0 W	s	7.2
	Dec 17	10 58 30	52.5 N	171.5 E	s	7.6
1930	Mar 26	07 12 05	7.5 S	125.5 E	40	7.2
	May 5	13 45 57	17.0 N	96.5 E	s	7.3
	6	22 34 23	38.0 N	44.5 E	s	7.2
	Jun 11	00 49 35	5.5 S	150.0 E	s	7.1
	Jul 2	21 03 42	25.5 N	90.0 E	s	7.1
	22	19 25 53	44.8 N	147.5 E	140	7.1
	Aug 18	09 53 41	55.0 S	27.0 W	50	7.1
	Oct 24	20 15 11	18.5 N	147.0 E	s	7.1
	Nov 25	19 02 47	35.0 N	139.0 E	s	7.1
	Dec 3	18 51 44	18.0 N	96.5 E	s	7.3
1931	Jan 15	01 50 41	16.0 N	96.8 W	s	7.9
	27	20 09 13	25.6 N	96.8 E	s	7.6
	28	21 24 03	11.0 N	144.8 E	s	7.2
	Feb 2	22 46 42	39.5 S	177.0 E	s	7.9
	10	06 34 25	5.3 S	102.5 E	s	7.1
	13	01 27 16	39.5 S	177.0 E	s	7.1

Year	Date	GMT	La	Long	Depth	Magnitude
		h m s	deg	deg	km	
1931	Feb 20	05 33 24	44.3 N	135.5 E	350	7.4
	Mar 2	02 18 34	22.0 S	172.0 E	110	7.1
	9	03 48 50	40.5 N	142.5 E	s	7.7
	18	08 02 23	32.5 S	72.0 W	s	7.1
	18	20 13 34	5.8 N	126.3 E	50	7.0
	26	12 38 37	7.0 S	129.5 E	80	7.3
	May 20	02 22 49	37.5 N	16.0 W	s	7.1
	Jul 21	03 36 22	21.0 S	170.0 E	140	7.0
	Aug 7	02 11 30	4.0 S	142.0 E	s	7.1
	10	21 18 40	47.0 N	90.0 E	s	7.9
	18	14 21 00	47.0 N	90.0 E	s	7.2
	24	21 35 22	30.3 N	67.8 E	s	7.0
	27	15 27 17	29.8 N	67.3 E	s	7.4
	Sep 9	20 36 26	19.0 N	145.5 E	180	7.1
	25	05 59 44	5.0 S	102.8 E	s	7.4
	Oct 3	19 13 13	10.5 S	161.8 E	s	8.1
	3	21 55 10	11.0 S	163.0 E	s	7.0
	3	22 47 40	11.0 S	161.5 E	s	7.3
	10	00 19 53	10.0 S	161.0 E	s	7.7
	Nov 2	10 02 59	32.0 N	131.5 E	s	7.5
1932	Jan 9	10 21 42	6.2 S	154.5 E	380	7.3
	29	13 41 17	6.0 S	155.0 E	s	7.0
	May 14	13 11 00	0.5 N	126.0 E	s	8.3
	26	16 09 40	25.5 S	179.3 E	600	7.9
	Jun 3	10 36 50	19.5 N	104.3 W	s	8.1
	18	10 12 10	19.5 N	103.5 W	s	7.9

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg		
1932	Aug 14	04 39 32	26.0 N	95.5 E	120	7.0
	Nov 13	04 47 00	43.8 N	137.0 E	320	7.0
	Dec 4	08 11 12	2.5 N	121.0 E	s	7.1
	21	06 10 05	38.8 N	116.0 W	s	7.2
	25	02 04 24	39.3 N	96.5 E	s	7.6
1933	Jan 1	08 48 39	14.8 S	168.0 E	140	7.0
	21	19 21 10	33.0 S	57.5 E	s	7.0
	Feb 23	08 09 12	20.0 S	71.0 W	40	7.6
	Mar 2	17 30 54	39.3 N	144.5 E	s	8.9
	Apr 27	02 36 04	61.3 N	150.6 W	s	7.0
	Jun 18	21 37 29	38.5 N	143.0 E	s	7.3
	24	21 54 46	5.5 S	104.8 E	s	7.5
	Aug 25	07 50 25	31.8 N	103.5 E	s	7.4
	28	22 19 40	59.5 S	25.0 W	s	7.4
	Sep 6	22 08 29	21.5 S	179.8 W	600	7.1
	Oct 25	23 28 16	23.0 S	66.7 W	220	7.0
	Nov 20	23 21 32	73.0 N	70.8 W	s	7.3
	1934 Jan 15	08 43 18	26.5 N	86.5 E	s	8.4
1934	Feb 14	03 59 34	17.5 N	119.0 E	s	7.9
	24	06 23 40	22.5 N	144.0 E	s	7.3
	28	14 21 42	5.0 S	150.0 E	s	7.2
	Mar 1	21 45 25	40.0 S	72.5 W	120	7.1
	5	11 46 15	40.5 S	175.5 E	s	7.5
	24	12 04 26	10.0 S	161.5 E	s	7.1
	Apr 15	22 15 13	7.8 N	127.0 E	s	7.3

Year	Date	GMT			Lat	Long	Depth	Magnitude
		h	m	s				
1934	May 1	07	04	56	3.5 N	97.5 E	145	7.0
	4	04	36	07	61.3 N	147.5 W	80	7.2
	Jun 13	22	10	28	27.5 N	62.5 E	80	7.0
	Jul 18	01	36	24	8.0 N	82.5 W	s	7.7
	18	19	40	15	11.8 S	166.5 E	s	8.1
	19	01	27	26	0.5 S	133.3 E	s	7.0
	21	06	18	18	11.0 S	165.8 E	s	7.3
	Oct 10	15	42	06	23.5 S	180.0	540	7.3
	Nov 30	02	05	10	18.5 N	105.5 W	s	7.0
	Dec 15	01	57	37	31.3 N	89.3 E	s	7.1
	31	18	45	45	32.0 N	114.8 W	s	7.0
1935	Jan 1	13	21	00	17.5 S	174.5 W	300	7.1
	Apr 19	15	23	22	31.5 N	15.3 E	s	7.1
	20	22	01	54	24.3 N	120.8 E	s	7.1
	May 14	23	23	10	59.0 S	26.5 W	155	7.0
	30	21	32	46	29.5 N	66.8 E	s	7.5
	Jun 24	23	23	14	15.8 S	167.8 E	140	7.1
	Jul 29	07	38	53	20.8 S	178.0 W	510	7.2
	Aug 3	01	10	01	4.5 N	96.3 E	s	7.0
	17	01	44	42	22.5 S	171.0 E	120	7.2
	Sep 4	01	37	41	22.3 N	121.3 E	s	7.2
	9	06	17	30	6.0 N	141.0 E	s	7.0
	11	14	04	02	43.0 N	146.5 E	60	7.6
	20	01	46	33	3.5 S	141.8 E	s	7.9
	20	05	23	01	3.3 S	142.5 E	s	7.0

Year	Date	GMT			Lat	Long	Depth	Magnitude
		h	m	s				
1935	Oct 2	05	33	00	43.5 N	146.5 E	70	7.0
	12	16	45	22	40.3 N	143.3 E	s	7.1
	18	00	11	56	40.5 N	143.8 E	s	7.2
	18	11	05	23	12.5 N	141.5 E	50	7.1
	Dec 14	22	05	17	14.8 N	92.5 W	s	7.3
	15	07	07	48	9.8 S	161.0 E	s	7.6
	17	19	17	35	22.5 N	125.5 E	s	7.2
	28	02	35	22	0.0	98.3 E	s	8.1
1936	Jan 2	22	34	30	0.0	99.5 E	60	7.0
	14	05	36	30	60.0 S	22.0 W	50	7.2
	20	16	56	19	6.0 N	127.0 E	80	7.1
	Feb 15	12	46	57	4.5 S	133.0 E	s	7.3
	22	15	31	54	49.5 S	164.0 E	s	7.2
	Apr 1	02	09	15	4.5 N	126.5 E	s	7.7
	19	05	07	17	7.5 S	156.0 E	40	7.4
	May 27	06	19	19	28.5 N	83.5 E	s	7.0
	Jun 30	15	06	38	50.5 N	160.0 E	s	7.4
	Jul 5	18	55	13	6.3 N	126.8 E	60	7.3
	17	11	12	15	24.5 S	70.0 W	60	7.3
	Aug 22	06	51	35	22.3 N	120.8 E	s	7.2
	23	21	12	13	5.0 N	95.0 E	40	7.3
	Sep 19	01	01	47	3.8 N	97.5 E	s	7.2
	Oct 5	09	44	24	1.5 N	126.8 E	s	7.1
	Nov 2	20	45	56	38.3 N	142.3 E	s	7.3
	13	12	31	27	55.5 N	163.0 E	s	7.2

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1936	Dec 29	14 47 56	4.5 S	153.5 E	100	7.0
1937	Jan 7	13 20 35	35.5 N	98.0 E	s	7.6
	23	10 55 51	4.5 S	153.0 E	s	7.0
	25	06 34 00	10.0 S	163.0 E	s	7.1
	Feb 21	07 02 35	44.5 N	149.5 E	s	7.4
	Apr 16	03 01 37	21.5 S	177.0 W	400	8.1
	Jul 2	02 37 15	14.3 S	167.0 E	80	7.0
	19	19 35 24	1.5 S	76.5 W	190	7.1
	22	17 09 29	64.8 N	146.8 W	s	7.3
	26	03 47 11	18.4 N	95.8 W	100	7.3
	26	19 56 37	38.5 N	141.5 E	90	7.1
	Aug 11	00 55 54	6.3 S	116.5 E	610	7.2
	20	11 59 16	14.5 N	121.5 E	s	7.5
	Sep 1	08 38 59	32.0 S	180.0	120	7.0
	3	18 48 12	52.5 N	177.5 W	80	7.3
	8	00 40 01	57.0 S	27.0 W	130	7.2
	15	12 27 32	10.5 S	161.5 E	80	7.3
	23	13 06 00	6.0 S	154.0 E	60	7.4
	27	08 55 10	9.5 S	111.0 E	s	7.2
	Nov 14	10 58 12	36.5 N	70.5 E	240	7.2
	Dec 8	08 32 09	23.0 N	121.5 E	s	7.0
	23	13 17 56	16.8 N	98.5 W	s	7.5
1938	Jan 24	10 31 44	61.0 S	38.0 W	s	7.1
	Feb 1	19 04 18	5.3 S	130.5 W	s	8.6
	5	02 23 34	4.5 N	76.3 W	160	7.0

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1938	May 12	15 38 57	6.0 S	147.0 E	s	7.5
	19	17 08 21	1.0 S	120.0 E	s	7.9
	23	07 19 28	36.5 N	141.0 E	s	7.4
	23	08 21 53	18.0 N	119.5 E	80	7.0
	30	14 29 50	20.5 S	169.5 E	70	7.0
	Jun 9	19 15 11	3.5 S	126.5 E	60	7.2
	10	09 53 39	25.5 N	125.0 E	s	7.7
	16	02 15 15	27.5 N	129.5 E	s	7.4
	Aug 16	04 27 50	23.5 N	94.3 E	s	7.2
	Sep 7	04 03 18	23.8 N	121.5 E	s	7.0
	Oct 10	20 48 05	2.3 N	126.8 E	s	7.3
	20	02 19 27	9.0 S	123.0 E	90	7.3
	Nov 5	08 43 21	36.8 N	141.8 E	60	7.7
	5	10 50 15	37.3 N	141.8 E	60	7.7
	6	08 53 53	37.3 N	142.3 E	60	7.6
	6	21 38 47	36.5 N	142.0 E	60	7.1
	10	20 18 43	55.5 N	158.0 W	s	8.7
	13	22 31 30	37.0 N	142.5 E	50	7.0
	17	03 54 34	55.5 N	158.5 W	s	7.2
	30	02 29 50	37.3 N	141.0 E	50	7.0
	Dec 6	23 00 53	22.8 N	120.8 E	s	7.0
	16	17 21 25	45.0 S	167.0 E	60	7.0
1939	Jan 25	03 32 14	36.3 S	72.3 W	60	8.3
	30	02 18 27	6.5 S	155.5 E	s	7.9
	Feb 3	05 26 20	10.5 S	159.0 E	s	7.1

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1939	Mar 21	01 11 09	1.5 S	89.5 E	s	7.2
	Apr 5	16 42 40	19.5 S	168.0 E	70	7.1
	18	06 22 45	27.0 S	70.5 W	100	7.4
	21	04 29 04	47.5 N	139.8 E	520	7.0
	30	02 55 30	10.5 S	158.5 E	s	8.1
	May 1	05 58 33	40.0 N	139.8 E	s	7.0
	8	01 46 50	37.0 N	24.5 W	s	7.1
	Jun 2	03 33 15	5.0 N	127.0 E	60	7.0
	8	20 46 53	15.5 S	174.0 W	100	7.2
	Jul 20	02 23 00	22.0 S	179.5 W	650	7.0
	Aug 12	02 07 27	16.3 S	168.5 E	180	7.2
	Oct 10	18 31 59	38.5 N	143.0 E	s	7.4
	17	06 22 06	14.0 S	167.8 E	120	7.4
	Dec 16	10 46 32	43.8 N	147.8 E	75	7.1
	21	20 54 48	10.0 N	85.0 W	s	7.3
	21	21 00 40	0.0	123.0 E	150	8.6
	26	23 57 21	39.5 N	38.5 E	s	7.9
1940	Jan 6	14 03 24	22.0 S	171.0 E	90	7.2
	17	01 15 00	17.0 N	148.0 E	80	7.3
	Feb 7	17 16 02	51.5 N	175.0 E	70	7.0
	20	02 18 20	13.5 S	167.0 E	200	7.0
	Apr 16	06 07 43	52.0 N	173.5 E	s	7.1
	16	06 43 07	52.0 N	173.5 E	s	7.2
	May 24	16 33 57	10.5 S	77.0 W	60	8.4
	Jul 10	05 49 55	44.0 N	131.0 E	580	7.3

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1940	Jul 14	05 52 53	51.8 N	177.5 E	80	7.75
	Aug 1	15 08 21	44.5 N	139.0 E	s	7.7
	22	05 27 18	53.0 N	165.5 W	s	7.2
	Sep 12	13 17 10	4.5 S	153.0 E	40	7.0
	19	18 19 48	24.0 S	171.0 E	80	7.0
	Oct 4	07 54 42	22.0 S	71.0 W	75	7.3
	7	06 43 04	5.0 N	126.0 E	100	7.0
	11	18 41 13	41.5 S	74.5 W	s	7.0
	Nov 10	01 39 09	45.8 N	26.5 E	150	7.4
	19	15 01 40	39.0 N	141.8 E	50	7.1
	Dec 22	18 59 46	15.5 S	68.5 W	230	7.1
	28	16 37 44	18.0 N	147.5 E	80	7.3
	1941 Jan 5	18 47 05	2.0 N	122.0 E	50	7.0
	13	16 27 38	4.5 S	152.5 E	s	7.0
	Apr 3	15 21 39	22.5 S	66.0 W	260	7.2
	7	23 29 17	17.8 N	78.5 W	s	7.1
	15	19 09 56	18.0 N	103.0 W	s	7.7
	May 17	02 24 50	10.0 S	166.3 E	s	7.4
	Jun 26	11 52 03	12.5 N	92.5 E	60	8.7
	Aug 2	11 41 26	28.5 S	178.0 W	s	7.1
	Sep 4	10 21 44	4.8 S	154.0 E	90	7.1
	12	07 02 04	0.5 S	132.5 E	s	7.0
	16	21 39 05	28.8 S	177.5 W	s	7.0
	17	06 47 57	0.5 S	121.5 E	190	7.1
	18	13 14 09	13.8 S	72.3 W	100	7.0

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1941	Sep 24	01 01 24	51.0 N	158.0 E	75	7.0
	Nov 8	23 37 22	0.5 N	122.0 E	s	7.3
	15	04 19 54	59.0 S	27.5 W	80	7.0
	18	10 14 36	61.0 S	58.0 W	s	7.0
	18	16 46 22	32.0 N	132.0 E	s	7.9
	24	21 46 23	28.0 S	177.5 W	80	7.3
	25	18 03 55	37.5 N	18.5 W	s	8.4
	Dec 5	20 46 58	8.5 N	83.0 W	s	7.5
	16	19 19 39	21.5 N	120.5 E	s	7.1
	26	14 48 04	21.5 N	99.0 E	s	7.0
1942	Jan 27	13 29 08	4.5 S	135.0 E	s	7.1
	29	09 23 44	19.0 S	169.0 E	130	7.1
	Feb 21	07 07 43	38.0 N	142.0 E	60	7.1
	Apr 8	15 40 24	13.5 N	121.0 E	s	7.9
	May 14	02 13 18	0.8 S	81.5 W	s	8.3
	28	01 01 48	0.0	124.0 E	120	7.5
	Jun 14	03 09 45	15.0 N	145.0 E	80	7.0
	18	09 30 57	9.0 N	140.5 E	s	7.1
	24	11 16 29	41.0 S	175.5 E	s	7.1
	Jul 8	06 55 45	24.0 S	70.0 W	140	7.0
	29	22 49 15	2.0 S	128.5 E	s	7.0
	Aug 1	12 34 03	41.0 S	175.8 E	50	7.1
	1	14 30 05	48.0 S	99.0 E	s	7.0
	6	23 36 59	14.0 N	91.0 W	60	8.3
	23	06 35 21	53.0 N	162.5 E	60	7.0

Year	Date	GMT h m s	Lat deg	Long deg	Depth km	Magnitude
1942	Aug 24	22 50 27	15.0 S	76.0 W	60	8.6
	Sep 9	01 25 26	53.0 N	164.5 W	80	7.0
	14	11 31 01	22.0 S	171.5 E	130	7.0
	Oct 20	23 21 44	8.5 N	122.5 E	s	7.3
	26	21 09 13	45.5 N	151.5 E	60	7.2
	Ncv 10	11 41 27	49.5 S	32.0 W	s	8.3
	15	17 12 00	37.0 N	141.5 E	s	7.0
	26	14 27 28	45.5 N	150.0 E	110	7.4
	28	10 38 45	7.5 N	36.0 W	s	7.1
	Dec 19	23 10 40	31.5 N	142.5 E	s	7.0
	20	14 03 08	40.5 N	36.5 E	s	7.3
1943	Feb 16	07 28 35	15.0 S	72.0 W	190	7.0
	22	09 20 45	17.8 N	101.5 W	s	7.5
	28	12 54 33	36.5 N	70.5 E	210	7.0
	Mar 9	09 48 55	60.0 S	27.0 W	s	7.3
	14	17 11 00	22.0 S	169.5 E	s	7.1
	14	18 37 56	20.0 S	69.5 W	150	7.2
	21	20 55 43	5.8 S	152.3 E	s	7.3
	25	18 27 15	60.0 S	27.0 W	s	7.3
	Apr 1	14 18 08	6.5 S	105.5 E	s	7.0
	6	16 07 15	30.8 S	72.0 W	60	8.3
	9	08 48 59	19.0 W	146.0 E	170	7.0
	May 2	17 18 09	6.5 N	80.0 W	s	7.1
	3	01 59 12	12.5 N	125.5 W	s	7.4
	25	23 07 36	7.5 N	128.0 E	s	8.1

Year	Date	GMT			Lat	Long	Depth	Magnitude
		h	m	s				
1943	Jun 8	20	42	46	1.0 S	101.0 E	50	7.4
	9	03	06	22	1.0 S	101.0 E	50	7.6
	13	05	11	49	42.8 N	143.3 E	60	7.4
	Jul 11	02	10	25	32.5 S	178.5 W	180	7.0
	23	14	53	09	9.5 S	110.0 E	90	8.1
	29	03	02	16	19.3 N	67.5 W	s	7.9
	Aug 1	16	18	41	20.0 S	170.0 E	230	7.0
	Sep 6	03	41	30	53.0 S	159.0 E	s	7.9
	10	08	36	53	35.3 N	134.0 E	s	7.4
	14	02	01	12	22.0 S	171.0 E	50	7.5
	14	03	47	15	22.0 S	170.0 E	50	7.5
	14	07	18	08	30.0 S	177.0 W	60	7.6
	27	22	03	44	30.0 S	178.0 W	90	7.1
	Oct 21	23	08	13	15.0 S	177.5 W	s	7.0
	23	17	23	16	26.0 N	93.0 E	s	7.2
	24	16	04	36	22.0 S	174.0 W	s	7.0
	Nov 2	18	08	22	57.0 S	26.0 W	s	7.2
	3	14	32	17	61.8 N	151.0 W	s	7.3
	6	08	31	37	6.0 S	134.5 E	s	7.6
	13	18	43	57	19.0 S	170.0 E	s	7.2
	17	14	57	17	33.5 N	138.0 E	300	7.0
	26	21	25	22	2.5 S	100.0 E	130	7.1
	26	22	20	36	41.0 N	34.0 E	s	7.6
	Dec 1	06	04	55	4.8 S	144.0 E	120	7.2

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1943	Dec 1	10 34 46	19.5 S	69.8 W	80	7.0
	23	19 00 10	5.5 S	153.5 E	50	7.3
1944	Jan 5	21 12 43	3.5 S	102.0 E	60	7.0
	7	02 49 20	4.5 S	143.5 E	120	7.1
	15	23 49 30	31.3 S	68.8 W	50	7.4
	Feb 1	03 22 36	41.5 N	32.5 E	s	7.4
	29	03 41 53	14.5 S	70.5 W	200	7.0
	29	16 28 07	0.5 N	76.0 E	s	7.2
	Mar 9	22 12 58	44.1 N	84.0 E	s	7.2
	22	00 43 18	8.5 S	123.5 E	220	7.5
	31	02 51 43	7.0 S	130.5 E	60	7.0
	Apr 26	01 54 15	1.0 S	134.0 E	50	7.2
	27	14 38 09	0.5 S	133.5 E	50	7.4
	May 19	00 19 19	2.5 S	152.8 E	50	7.2
	25	01 06 37	21.5 S	179.5 W	640	7.2
	25	12 58 05	2.5 S	152.8 E	s	7.5
	Jun 21	10 58 20	22.0 S	169.0 E	50	7.2
	28	07 58 54	15.0 N	92.5 W	s	7.0
	Jul 27	00 04 23	54.0 N	165.5 W	70	7.1
	Sep 3	19 11 29	57.0 S	122.0 W	s	7.0
	11	09 45 22	1.5 N	127.0 E	40	7.2
	23	12 13 20	54.0 N	160.0 E	40	7.4
	27	16 25 02	39.0 N	73.5 E	40	7.0
	Oct 2	20 29 51	42.5 N	142.5 E	75	7.0

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1944	Oct 5	17 28 27	22.5 S	172.0 E	120	7.5
	Nov 15	20 47 01	4.5 N	127.5 E	s	7.2
	16	12 10 58	12.5 S	167.0 E	s	7.3
	24	04 49 03	19.0 S	169.0 E	170	7.5
	29	18 51 21	19.0 S	169.0 E	170	7.0
	Dec 7	04 35 42	33.8 N	136.0 E	s	8.3
	10	16 24 58	18.0 S	168.0 E	50	7.3
	12	04 17 10	51.5 N	179.5 E	s	7.0
	27	15 25 49	6.5 S	152.0 E	90	7.0
	1945 Jan 12	18 38 26	34.8 N	136.8 E	s	7.1
	Feb 1	10 35 51	22.0 S	170.0 E	60	7.0
	1	12 13 40	22.0 S	170.0 E	60	7.25
	10	04 57 56	41.3 N	142.5 E	50	7.3
	18	10 08 07	42.0 N	143.0 E	50	7.0
	26	22 14 27	26.0 N	143.5 E	50	7.1
	Mar 11	21 37 50	37.0 N	142.0 E	50	7.2
	23	23 14 13	62.0 S	153.0 E	s	7.1
	Apr 15	02 35 22	57.0 N	164.0 E	s	7.0
	19	13 03 58	21.0 S	169.5 E	40	7.0
	Jun 22	09 18 40	44.0 N	146.0 E	120	7.0
	27	13 08 20	27.0 N	111.0 W	s	7.0
	Jul 15	05 35 13	17.5 N	146.5 E	120	7.1
	Aug 29	10 22 40	15.0 S	168.0 E	50	7.2
	Sep 1	22 44 10	46.5 S	165.5 E	s	7.2
	5	21 48 45	5.0 S	153.5 E	50	7.1
	9	04 03 54	17.0 S	167.0 E	60	7.0

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1945	Sep 13	11 17 11	33.3 S	70.5 W	100	7.1
	22	09 10 05	4.0 S	147.0 E	50	7.0
	Oct 9	14 36 33	43.5 N	147.5 E	80	7.0
	16	16 02 58	0.3 S	125.0 E	50	7.1
	Nov 26	05 13 10	21.0 S	180.0	600	7.0
	27	21 56 50	24.5 N	63.0 E	s	8.3
	Dec 8	01 04 02	6.5 S	151.0 E	s	7.1
	27	04 41 05	6.0 S	151.0 E	40	7.0
	28	17 48 45	6.0 S	150.0 E	s	7.8
1946	Jan 5	19 57 20	16.0 S	167.0 E	50	7.3
	11	01 33 29	44.0 N	129.5 E	580	7.2
	12	20 25 37	59.3 N	147.3 W	50	7.2
	17	09 39 35	7.5 S	147.5 E	100	7.2
	20	16 54 21	17.5 S	167.5 E	s	7.0
	Apr 1	12 28 54	52.8 N	163.5 W	s	7.4
	11	01 52 20	1.0 S	14.5 W	s	7.2
	May 3	22 23 43	6.0 S	154.0 E	s	7.4
	8	05 20 22	0.0	99.5 E	s	7.1
	21	09 16 42	14.5 N	60.5 W	50	7.0
	Jun 7	04 13 20	16.5 N	94.0 W	100	7.1
	23	17 13 22	49.8 N	124.5 W	s	7.3
	Jul 9	13 13 50	19.0 S	169.0 E	170	7.0
	11	04 46 42	17.0 N	94.5 W	130	7.1
	Aug 2	19 18 48	26.5 S	70.5 W	60	7.9
	4	17 51 05	19.3 N	69.0 W	s	8.1

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1946	Aug 8	13 28 28	19.5 N	69.5 W	s	7.9
	21	18 00 18	24.0 S	177.0 W	100	7.0
	28	22 28 15	26.0 S	63.0 W	580	7.2
	Sep 12	15 17 15	23.5 N	96.0 E	s	7.5
	12	15 20 20	23.5 N	96.0 E	s	7.75
	23	23 30 00	6.0 S	145.0 E	100	7.2
	26	10 53 15	25.0 S	179.0 E	600	7.0
	29	03 01 55	4.5 S	153.5 E	s	7.75
	30	00 59 40	13.0 S	76.0 W	70	7.0
	Oct 4	14 45 26	18.8 N	68.5 W	50	7.0
	26	00 21 03	60.0 S	35.0 W	s	7.0
	Nov 1	11 14 24	51.5 N	174.5 W	40	7.0
	2	18 28 25	41.5 N	72.5 E	s	7.6
	4	21 47 47	39.8 N	54.5 E	s	7.5
	10	17 42 53	8.5 S	77.5 W	s	7.25
	12	17 28 41	20.0 S	173.5 W	s	7.25
	Dec 20	19 19 05	32.5 N	134.5 E	s	8.4
	21	10 18 49	44.0 N	149.0 E	s	7.2
1947	Jan 3	02 20 33	44.3 N	149.0 E	40	7.0
	26	10 06 46	12.5 N	86.3 W	170	7.2
	29	08 17 50	26.0 S	63.0 W	580	7.25
	Feb 7	08 40 35	10.0 S	161.5 E	50	7.0
	Mar 2	19 09 26	5.0 S	144.5 E	50	7.0
	17	08 19 32	33.0 N	99.5 E	s	7.7
	25	20 32 14	38.8 S	178.5 E	s	7.0
	Apr 2	05 39 11	1.5 S	138.0 E	s	7.4

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1947	Apr 14	07 15 33	44.0 N	148.5 E	s	7.0
	24	19 35 14	8.5 N	39.0 W	50	7.0
	May 6	20 30 32	6.5 S	148.5 E	s	7.6
	27	05 58 54	1.5 S	135.3 E	s	7.25
	Jun 12	09 02 30	1.5 N	126.5 E	40	7.2
	13	20 24 49	21.5 N	145.5 E	s	7.2
	19	07 34 37	22.0 N	145.5 E	s	7.0
	Jul 29	13 43 22	28.5 N	94.0 E	60	7.9
	Aug 5	14 24 10	25.5 N	63.0 E	s	7.3
	Sep 26	16 01 57	24.8 N	123.0 E	110	7.4
	Oct 6	19 55 37	37.0 N	22.0 E	s	7.0
	16	02 09 47	64.5 N	147.5 W	s	7.0
	Nov 1	14 58 53	10.5 S	75.0 W	s	7.3
	4	00 09 10	44.0 N	140.5 E	s	7.1
	9	04 57 50	22.5 S	170.0 E	50	7.1
	Dec 15	19 20 26	59.5 S	160.0 W	60	7.2
	24	05 22 00	54.0 S	114.0 E	60	7.0
1948	Jan 4	08 56 37	20.8 S	179.0 W	600	7.0
	6	17 23 26	17.0 N	98.0 W	80	7.0
	6	17 25 58	17.0 N	98.0 W	80	7.0
	22	13 55 21	22.0 S	177.0 W	140	7.0
	24	17 46 40	10.5 N	122.0 E	s	8.3
	27	11 58 28	20.5 S	178.0 W	630	7.2
	28	03 47 21	1.5 N	126.5 E	80	7.2
	Feb 9	12 58 15	35.5 N	27.0 E	40	7.1

Year	Date	GMT			Lat	Long	Depth	Magnitude
		h	m	s				
					deg	deg	km	
1948	Feb 9	14	54	22	0.0	122.5 E	160	7.2
	Mar 1	01	12	28	3.0 S	127.5 E	60	7.9
	3	09	09	54	18.5 N	119.0 E	s	7.2
	13	20	02	35	1.5 N	126.5 E	60	7.1
	Apr 17	16	11	28	33.0 N	135.8 E	s	7.3
	21	20	12	02	19.3 N	69.3 W	40	7.3
	May 11	08	55	41	17.5 S	70.3 W	70	7.3
	14	22	31	43	54.5 N	161.0 W	s	7.5
	25	07	11	21	29.5 N	100.5 E	s	7.3
	Jun 28	07	13	30	36.5 N	136.0 E	s	7.3
	29	10	28	37	15.5 S	172.5 W	60	7.0
	Jul 20	11	02	17	17.0 S	75.0 W	70	7.1
	Aug 25	06	09	24	24.5 S	65.0 W	50	7.0
	Sep 2	23	34	50	10.0 N	125.5 E	s	7.0
	8	15	09	11	21.0 S	174.0 W	s	7.9
	10	13	48	34	43.5 N	147.0 E	40	7.1
	Oct 5	20	12	05	37.5 N	58.0 E	s	7.3
	Nov 19	01	04	24	10.0 N	83.5 W	80	7.0
	26	05	36	37	5.0 S	145.0 E	70	7.0
1949	Jan 24	09	15	48	22.0 S	176.0 W	110	7.0
	Feb 2	17	41	29	53.0 N	173.0 W	220	7.0
	13	18	24	24	33.5 S	178.0 W	60	7.2
	23	16	08	08	41.0 N	83.5 E	s	7.3
	28	00	13	04	57.0 S	29.0 W	60	7.0
	Mar 4	10	19	25	36.0 N	70.5 E	230	7.5
	16	22	15	13	5.5 S	151.0 E	60	7.0

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1949	Mar 17	21 05 03	5.5 S	151.0 E	60	7.0
	27	06 34 05	3.5 N	127.5 E	s	7.0
	Apr 13	19 55 43	47.3 N	122.5 W	60	7.0
	20	03 29 07	38.0 S	73.5 W	70	7.3
	23	11 15 39	8.0 S	121.0 E	60	7.1
	25	13 54 59	19.8 S	69.0 W	110	7.3
	30	01 23 32	6.5 N	125.0 E	130	7.4
	Jul 2	19 57 13	16.0 N	148.0 E	50	7.1
	10	03 53 36	39.0 N	70.5 E	s	7.6
	23	10 26 45	18.5 S	170.0 E	150	7.2
	27	15 11 42	28.0 S	177.0 W	70	7.0
	Aug 6	00 35 37	18.5 S	174.5 W	70	7.5
	22	04 01 11	53.8 N	133.3 W	s	8.1
	Sep 14	19 50 20	0.8 N	126.0 E	50	7.2
	27	15 30 45	59.8 N	149.0 W	50	7.0
	Oct 19	21 00 19	5.5 S	154.0 E	60	7.25
	Nov 22	00 51 49	28.5 S	178.5 W	180	7.3
	27	08 42 18	18.0 S	173.0 W	60	7.2
	Dec 17	06 53 30	54.0 S	71.0 W	s	7.75
	17	15 07 55	54.0 S	71.0 W	s	7.75
1950	26	06 23 52	15.5 S	180.0	s	7.0
	27	23 57 16	60.0 S	22.0 W	50	7.1
	29	03 03 54	18.0 N	121.0 E	s	7.2
	Jan 30	00 56 32	53.5 S	71.5 W	s	7.0
	Feb 2	23 33 39	22.0 N	100.0 E	s	7.0
	28	10 20 57	46.0 N	144.0 E	340	7.9

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s				
1950	May 17	18 13 13	21.0 S	169.0 E	40	7.0
	25	18 35 07	13.0 N	143.5 E	90	7.0
	26	01 17 25	20.3 S	169.3 E	40	7.2
	Jun 6	16 07 32	47.0 S	15.0 W	60	7.1
	21	06 55 37	20.3 S	169.3 E	40	7.0
	24	22 25 34	20.5 S	169.5 E	40	7.2
	Jul 9	04 40 04	8.0 S	70.8 W	650	7.0
	9	04 50 05	8.0 S	70.8 W	650	7.0
	29	23 49 02	6.5 S	155.0 E	70	7.1
	Aug 14	22 51 24	27.4 S	62.5 W	630	7.25
	15	14 09 30	28.5 N	96.5 E	s	8.7
	Sep 10	15 16 08	15.5 S	167.0 E	100	7.1
	29	06 32 20	19.0 N	107.0 W	60	7.0
	Oct 5	16 09 31	11.0 N	85.0 W	s	7.7
	8	03 23 09	3.8 S	128.3 E	s	7.6
	23	16 13 20	14.5 N	91.5 W	s	7.1
	Nov 2	15 27 56	6.5 S	129.5 E	60	8.1
	8	02 18 12	10.0 S	159.5 E	s	7.25
	Dec 1	14 50 58	14.0 N	47.3 W	60	7.25
	2	19 51 49	18.3 S	167.5 E	60	8.1
	2	19 55 27	18.3 S	167.5 E	60	7.25
	4	16 28 03	5.0 S	153.5 E	110	7.2
	9	21 38 48	23.5 S	67.5 W	100	8.3
	10	02 50 42	14.3 S	75.8 W	80	7.0
	10	13 23 04	28.0 S	178.5 W	250	7.25
	14	01 52 49	19.3 S	175.8 W	200	7.9

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1950	Dec 14	14 15 51	17.0 N	97.5 W	s	7.3
1951	Feb 13	22 12 57	56.0 N	156.0 W	s	7.1
	17	21 07 07	7.0 S	146.0 E	180	7.3
	Mar 10	21 57 29	15.0 S	167.5 E	130	7.2
	23	21 38 51	30.5 S	180.0	270	7.0
	May 1	05 02 40	50.5 S	149.0 E	s	7.0
	21	08 27 20	6.0 S	154.5 E	150	7.0
	Jul 11	18 21 52	27.5 N	139.5 E	480	7.0
	Oct 21	21 34 14	23.8 N	121.5 E	s	7.3
	22	03 29 27	23.8 N	121.3 E	s	7.1
	22	05 43 01	24.0 N	121.3 E	s	7.1
	Nov 6	16 40 05	47.8 N	154.3 E	s	7.2
	18	09 35 47	30.5 N	91.0 E	s	7.9
	24	18 50 18	23.0 N	122.5 E	s	7.3
	Dec 8	04 14 12	34.0 S	57.0 E	s	7.9
1952	Feb 14	03 38 12	7.5 S	126.5 E	s	7.25
	26	11 31 00	14.0 S	70.5 W	260	7.0
	Mar 4	01 22 43	42.5 N	143.0 E	s	8.6
	9	17 03 47	42.5 N	143.0 E	s	7.1
	19	10 57 12	9.5 N	127.3 E	s	7.9
	May 9	17 47 41	6.5 S	155.0 E	50	7.0
	Jun 11	00 31 36	31.5 S	67.5 W	s	7.0
	Jul 21	11 52 14	35.0 N	119.0 W	s	7.7
	Aug 17	16 02 07	30.5 N	91.5 E	s	7.5
	Sep 21	02 30 35	21.8 S	65.8 W	260	7.2

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1952	Nov 4	16 58 26	52.8 N	159.5 E	s	6.4
	Dec 6	10 41 18	8.0 S	156.5 E	s	7.1
	24	18 39 38	5.5 S	152.0 E	s	7.0
1953	Jan 5	07 48 22	54.0 N	170.5 E	s	7.1
	5	10 06 30	19.0 N	155.5 E	40	7.0
	Feb 26	11 42 28	11.0 S	164.5 E	s	7.0
	Mar 18	19 06 14	40.0 N	27.3 E	s	7.25
	19	08 27 50	14.0 N	61.3 W	130	7.3
	Apr 23	16 24 17	4.0 S	154.0 E	s	7.5
	May 6	17 16 49	36.5 S	72.5 W	60	7.6
	Jun 25	10 45 00	8.5 S	124.0 E	50	7.1
	Jul 2	06 56 58	19.5 S	169.5 E	250	7.5
	Aug 12	09 23 53	38.3 N	20.3 E	s	7.1
	Nov 4	03 49 08	13.0 S	166.5 E	s	7.4
	17	13 29 53	13.8 N	92.0 W	40	7.1
	25	17 48 52	34.0 N	141.5 E	s	8.0
	Dec 7	02 05 37	22.0 S	68.0 W	110	7.1
	12	17 31 25	4.0 S	81.0 W	s	7.4
1954	Jan 13	00 13 10	48.5 S	165.5 E	s	7.0
	Feb 1	01 06 54	24.3 N	143.8 E	50	7.1
	11	00 30 15	39.0 N	101.5 E	s	7.25
	19	19 07 48	30.0 S	177.8 W	40	7.0
	20	18 35 05	6.8 S	124.5 E	580	7.0
	22	12 03 36	57.0 S	26.5 W	140	7.0
	Mar 3	06 02 55	5.8 S	142.5 E	s	7.0
	21	23 42 11	24.5 N	95.3 E	180	7.4

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1954	Mar 29	06 17 05	37.0 N	3.6 W	640	7.1
	31	18 25 47	12.5 N	58.0 E	s	7.25
	Apr 29	11 34 31	28.5 N	113.0 W	s	7.0
	30	13 02 37	39.0 N	22.0 E	s	7.0
	Jul 3	22 31 26	6.5 S	105.3 E	80	7.0
	Sep 17	11 03 18	21.5 S	177.0 W	2.0	7.0
	Dec 16	11 07 10	39.3 N	118.1 W	s	7.1
1955	Jan 5	00 50 14	50.0 S	164.0 E	s	7.0
	Feb 27	20 43 25	28.0 S	175.5 W	s	7.8
	Mar 14	13 12 04	52.5 N	173.5 W	75	7.0
	18	00 06 43	54.0 N	161.0 E	s	7.4
	22	14 05 05	8.5 S	92.0 E	s	7.1
	31	18 17 03	8.0 N	124.0 E	s	7.6
	Apr 14	01 29 04	29.5 N	102.0 E	s	7.4
	15	03 40 55	40.0 N	75.0 E	s	7.0
	19	20 24 07	30.0 S	72.0 W	s	7.1
	May 17	14 49 50	7.0 N	94.0 E	s	7.3
	26	16 23 14	10.0 S	161.0 E	s	7.0
	30	12 31 42	24.0 N	142.8 E	580	7.3
	Jun 14	06 11 18	20.0 N	107.0 W	s	7.0
	Aug 6	08 31 28	21.0 S	178.0 W	360	7.0
	16	11 47 03	6.0 S	155.0 E	210	7.0
	Sep 23	15 06 19	26.8 N	101.8 E	s	7.0
	Oct 10	08 57 47	5.0 S	152.5 E	s	7.3
	13	09 26 49	10.0 S	160.8 E	70	7.3
	Nov 23	06 29 30	51.0 N	157.3 E	70	7.1

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1956	Jan 8	20 54 16	19.0 S	70.5 W	40	7.1
	10	08 52 38	25.5 S	175.5 W	s	7.3
	16	23 37 40	0.5 S	80.5 W	s	7.3
	Feb 1	13 41 46	18.8 N	145.5 E	370	7.0
	18	07 34 22	30.0 N	137.5 E	480	7.3
	May 23	20 48 28	15.0 S	179.0 W	430	7.5
	Jun 9	23 13 52	35.0 N	67.5 E	s	7.6
	Jul 9	03 11 40	37.0 N	26.0 E	s	7.8
	16	15 07 07	22.3 N	96.0 E	s	7.0
	18	06 19 35	5.5 S	130.0 E	190	7.5
	Oct 11	02 24 35	46.0 N	151.0 E	110	7.6
	26	14 42 11	11.5 N	87.5 W	s	7.3
	Dec 18	02 31 03	25.5 S	71.0 W	s	7.0
	27	00 14 11	23.3 S	176.8 W	210	7.1
1957	Jan 2	03 48 14	53.0 N	168.0 W	s	7.0
	3	12 48 27	44.0 N	130.0 E	600	7.0
	Feb 23	20 26 11	24.0 N	122.0 E	s	7.3
	Mar 9	14 22 28	51.3 N	175.8 W	s	8.25
	9	20 30 15	52.5 N	169.5 W	s	7.1
	11	09 58 42	53.0 N	169.3 W	s	7.0
	11	14 55 19	51.5 N	178.5 W	s	7.2
	12	11 44 50	51.0 N	177.0 W	s	7.3
	14	14 47 45	51.5 N	177.0 W	s	7.2
	16	02 34 12	52.0 N	179.0 W	s	7.2
	22	14 21 06	54.0 N	166.0 W	s	7.0
	23	05 12 40	5.5 S	131.0 E	150	7.3

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1957	Apr 10	11 29 58	56.0 N	154.0 W	s	7.1
	14	19 18 01	15.5 S	173.0 W	s	7.5
	16	04 04 04	4.5 S	107.5 E	600	7.5
	19	22 19 26	52.0 N	166.5 W	50	7.3
	25	02 25 36	36.5 N	29.0 E	s	7.1
	May 21	01 11 58	21.5 N	144.0 E	100	7.0
	26	06 33 31	41.0 N	31.0 E	s	7.1
	Jun 11	14 49 47	30.0 S	178.0 W	100	7.0
	13	10 40 38	51.5 N	175.0 W	s	7.0
	22	23 50 23	1.5 S	137.0 E	s	7.3
	27	00 09 28	56.5 N	116.0 E	s	7.9
	Jul 2	00 42 23	36.0 N	53.0 E	s	7.1
	14	06 23 52	27.0 S	178.0 W	200	7.1
	28	08 40 04	17.0 N	99.0 W	s	7.9
	29	17 15 14	23.5 S	71.5 W	s	7.0
	Sep 24	08 21 05	5.5 N	127.5 E	s	7.6
	28	14 20 00	20.5 S	178.0 W	600	7.5
	Nov 29	22 19 38	21.0 S	66.0 W	170	7.8
	Dec 4	03 37 45	45.5 N	99.5 E	s	8.3
	13	01 44 59	34.5 N	48.0 E	s	7.2
	17	13 50 12	12.5 E	166.5 E	140	7.5
1958	Jan 15	19 14 29	16.5 S	71.5 W	60	7.3
	19	14 07 27	1.5 N	79.5 W	40	7.8
	Mar 11	00 25 56	25.5 N	125.0 E	70	7.5
	Apr 7	15 30 38	66.5 N	157.0 W	s	7.3
	May 31	19 32 30	15.0 S	169.0 E	s	7.2

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1958	Jul 10	06 15 51	58.6 N	137.1 W	s	7.9
	26	17 37 09	13.5 S	69.0 W	620	7.5
	Aug 15	22 29 17	1.5 N	125.0 E	170	7.0
	Nov 6	22 58 06	44.5 N	148.5 E	75	8.7
	12	20 23 26	44.5 N	148.5 E	40	7.3
1959	Feb 7	09 36 51	4.0 S	81.5 W	s	7.2
	Mar 1	16 49 13	0.5 S	134.5 E	100	7.0
	Apr 26	20 40 38	25.0 N	122.5 E	150	7.7
	May 4	07 15 42	52.5 N	159.5 E	60	8.25
	Jun 14	00 11 57	20.5 S	68.0 W	100	7.5
	Jul 19	15 06 10	15.0 S	70.5 W	200	7.0
	Aug 17	21 24 40	7.5 S	156.0 E	s	7.25
	18	06 37 15	44.8 N	111.1 W	s	7.1
	24	21 30 46	10.5 S	161.0 E	s	7.0
	Sep 14	14 09 39	28.5 S	177.0 W	s	7.7
	Nov 19	11 08 41	5.5 S	146.0 E	100	7.0
	Dec 14	23 21 56	59.5 S	91.0 W	s	7.0
1960	Jan 13	15 40 34	16.0 S	72.0 W	200	8.0
	15	09 30 24	15.0 S	75.0 W	150	7.0
	Mar 8	16 33 38	16.5 S	168.5 E	250	7.2
	20	17 07 30	40.0 N	143.5 E	60	7.0
	May 21	10 02 50	37.5 S	73.5 W	s	7.25
	22	10 32 43	37.5 S	73.0 W	s	7.2
	22	19 11 17	39.5 S	74.5 W	s	8.3
	Jun 20	02 01 08	38.0 S	73.5 W	s	7.0
	Jul 3	20 20 46	50.5 N	177.0 W	s	7.0

Year	Date	GMT	Lat	Long	Depth km	Magnitude
		h m s	deg	deg		
1960	Jul 25	11 12 00	54.0 N	159.0 E	100	7.0
	Oct 28	13 18 14	52.2 N	157.4 E	96	7.0
	Nov 1	08 45 59	38.5 S	75.1 W	55	7.2
	13	09 20 32	51.4 N	168.8 W	32	7.0
	24	06 52 41	24.4 S	176.1 W	23	7.0
	Dec 3	04 24 19	42.9 N	104.4 E	60	7.0
	13	07 36 16	52.7 S	159.1 E	25	7.25
1961	Jan 22	03 24 05	12.0 S	166.2 E	25	7.0
	Feb 26	18 10 49	31.6 N	131.2 E	54	7.2
	Mar 7	10 10 39	28.3 S	175.7 W	43	7.4
	Jul 23	21 51 08	18.5 S	168.3 E	44	7.2
	Aug 11	15 51 35	43.0 N	145.0 E	50	7.0
	19	05 09 50	10.8 S	71.0 W	649	7.0
	19	05 33 31	36.2 N	136.5 E	17	7.25
	31	01 48 38	10.7 S	70.9 W	626	7.2
	31	01 57 08	10.5 S	70.7 W	629	7.5
	Sep 1	00 09 35	59.5 S	27.3 W	131	7.5
1962	8	11 26 33	56.3 S	27.1 W	125	7.7
	Feb 14	06 36 05	37.8 S	72.5 W	45	7.25
	Mar 7	11 01 05	19.2 N	145.1 E	685	7.0
	17	20 47 32	10.9 N	43.2 W	33	7.0
	Apr 12	00 52 45	38.1 N	142.3 E	48	7.2
	23	05 58 05	42.9 N	143.4 E	25	7.2
	May 6	19 00 14	60.2 S	33.5 W	33	7.0
	11	14 11 54	17.0 N	99.6 W	40	7.0
	15	05 23 46	7.3 S	128.3 E	34	7.2

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1962	May 19	14 58 15	17.2 N	99.5 W	33	7.2
	21	12 02 50	37.3 N	96.0 E	25	7.2
	Jul 30	17 16 44	3.3 S	143.9 E	25	7.0
	Aug 3	08 56 12	23.2 S	67.5 W	71	7.1
	Sep 1	19 20 39	35.6 N	50.0 E	21	7.25
	18	00 29 05	7.5 N	82.3 W	33	7.0
1963	Feb 13	08 50 02	24.5 N	121.8 E	33	7.25
	26	20 14 09	7.5 S	146.2 E	171	7.25
	Mar 16	08 44 48	46.5 N	154.7 E	26	7.0
	26	09 48 20	29.7 S	177.8 W	45	7.0
	28	00 15 48	66.3 N	19.6 W	15	7.0
	Apr 16	01 29 19	0.8 S	128.0 E	33	7.0
	19	07 35 24	35.8 N	96.9 E	33	7.0
	May 1	10 03 20	19.0 S	169.0 E	140	7.0
	Aug 15	17 25 06	13.8 S	69.3 W	543	7.75
	Sep 15	00 46 54	10.3 S	165.6 E	43	7.25
	17	19 20 08	10.1 S	165.3 E	17	7.25
	24	16 30 16	10.6 S	78.0 W	80	7.0
	Oct 12	11 26 58	44.8 N	149.0 E	40	7.0
	13	05 17 58	44.8 N	149.5 E	60	8.25
	20	00 53 07	44.7 N	150.7 E	25	7.0
	Nov 9	21 15 30	9.0 S	71.5 W	600	7.0
	Dec 15	19 34 46	4.8 S	108.0 E	650	7.1
1964	Feb 6	13 07 25	55.7 N	155.8 W	33	7.1
	Mar 28	03 36 13	61.1 N	147.6 W	20	8.5
	Apr 23	03 32 50	5.3 S	134.0 E	33	7.2

Year	Date	GMT	Lat	Long	Depth	Magnitude
		h m s	deg	deg	km	
1964	May 7	07 58 14	40.4 N	139.0 E	33	7.0
	26	10 59 12	56.2 S	27.8 W	130	7.3
	31	00 40 36	43.5 N	146.8 E	48	7.4
	Jun 16	04 01 44	38.3 N	139.1 E	57	7.4
	23	01 26 37	43.3 N	146.1 E	77	7.6
	Jul 6	07 22 12	18.3 N	100.4 W	100	7.4
	9	16 39 49	15.5 S	167.6 E	121	7.2
	24	08 12 40	47.2 N	153.8 E	32	7.0
	Sep 12	22 07 03	49.1 S	164.2 E	33	7.3
	Nov 17	08 15 39	5.7 S	150.7 E	45	7.6

### FIGURE CAPTIONS

Fig. 1. Division of the circum-Pacific belt into regions.

Fig. 2. Dependence scheme between  $a$ ,  $b$ , and  $M_0$ .

Fig. 3. Recurrence diagrams for shallow (A) and shallow plus intermediate (B) earthquakes in the circum-Pacific and non-Pacific regions for 1918-1963 (solid lines correspond to observational data and dotted lines to least-square solutions).

Fig. 4. A)  $b$ -coefficients in shallow, and shallow plus intermediate earthquakes versus secular strain energy release per  $1^\circ$  of arc in shallow earthquakes.  
B) Maximum magnitudes in shallow earthquakes versus secular strain energy release per  $1^\circ$  of arc in shallow earthquakes.

Numerical values are given in Table II.

Fig. 5. Histograms of annual seismic energy release ( $E$ ) and annual number of earthquakes ( $v$ ) in the circum-Pacific belt (A,B,C) and in the non-Pacific regions (D,E). Averages are indicated by horizontal lines (see also Table III) and least-square solutions by sloping lines (formulas (9)-(12)).

**Fig. 1**

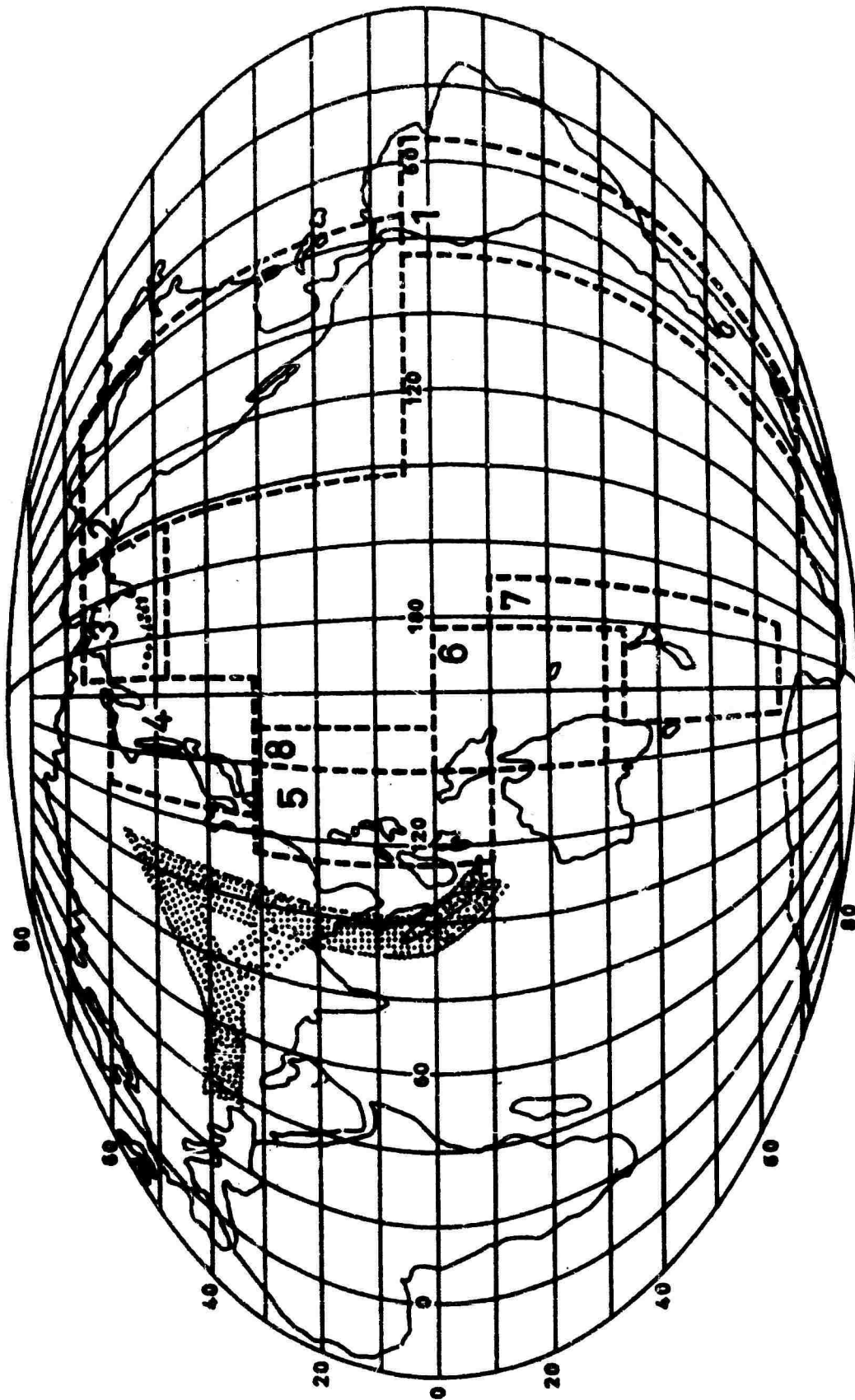


Fig. 2

